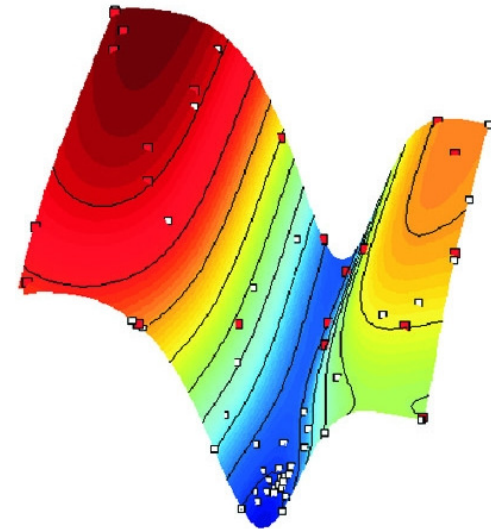

D-SPEX

an advanced post-processor for
optimization and stochastic investigations

Katharina Witowski
katharina.witowski@dynamore.de

Martin Liebscher
martin.liebscher@dynamore.de

Heiner Müllerschön
heiner.muellerschoen@dynamore.de



Overview

- § Introduction to D-SPEX
- § Optimization of an Adaptive Restraint System
 - Meta-model visualization
 - Visualization of constraints
 - Visualization of Pareto optimal solutions
- § DOE Sensitivity Analysis with LS-OPT
 - Feasibility
- § Application of Shape Optimization with LS-OPT
 - History curves and virtual histories
- § Stochastic Analysis – Front Crash
 - Anthill plots
 - PDF/CDF
 - Correlation matrix, Sobol indices
- § Conclusions

Introduction to D-SPEX

- § D-SPEX is a Matlab based post processing tool that is specialized on the visualization of meta-model data provided by LS-OPT
- § Matlab is not needed to run D-SPEX
- § D-SPEX has been developed in cooperation with AUDI AG
- § D-SPEX provides features that are not currently implemented in the LS-OPT viewer [↗](#) complement to the visualization capabilities of LS-OPT
- § D-SPEX provides features to visualize stochastic results

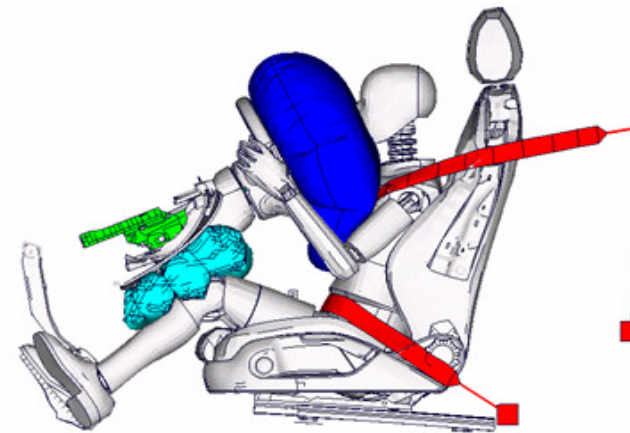
Optimization of a Adaptive Restraint System

§ Four load cases :

- “Hybrid III 5% Female” dummy, belted
- “Hybrid III 5% Female” dummy, not belted
- “Hybrid III 50% Male” dummy, belted
- “Hybrid III 50% Male” dummy, not belted

§ Design variables:

- upper force level
- the area of the vent holes
- trigger times of restraint system



Seat Belt Lock and Seat Weight Recognition available

Optimization of an Adaptive Restraint System

↳ Optimization Problem

■ Objectives

■ Minimize Thorax Acceleration

- > *min BrustA3ms-05a*
- > *min BrustA3ms-50a*
- > *min BrustA3ms-05p*
- > *min BrustA3ms-50p*

■ Constraints < regulation requirements

■ Head Injury Coefficient (15ms)

- > *HIC15-05a*
- > *HIC15-50a*
- > *HIC15-05p*
- > *HIC15-50p*

■ Femur Forces (left/right)

- > *FemurLi-05a*
- > *FemurLi-50a*
- > *FemurLi-05p*
- > *FemurLi-50p*

■ Thorax Intrusion

- > *BrustSx-05a*
- > *BrustSx-50a*
- > *BrustSx-05p*
- > *BrustSx-50p*

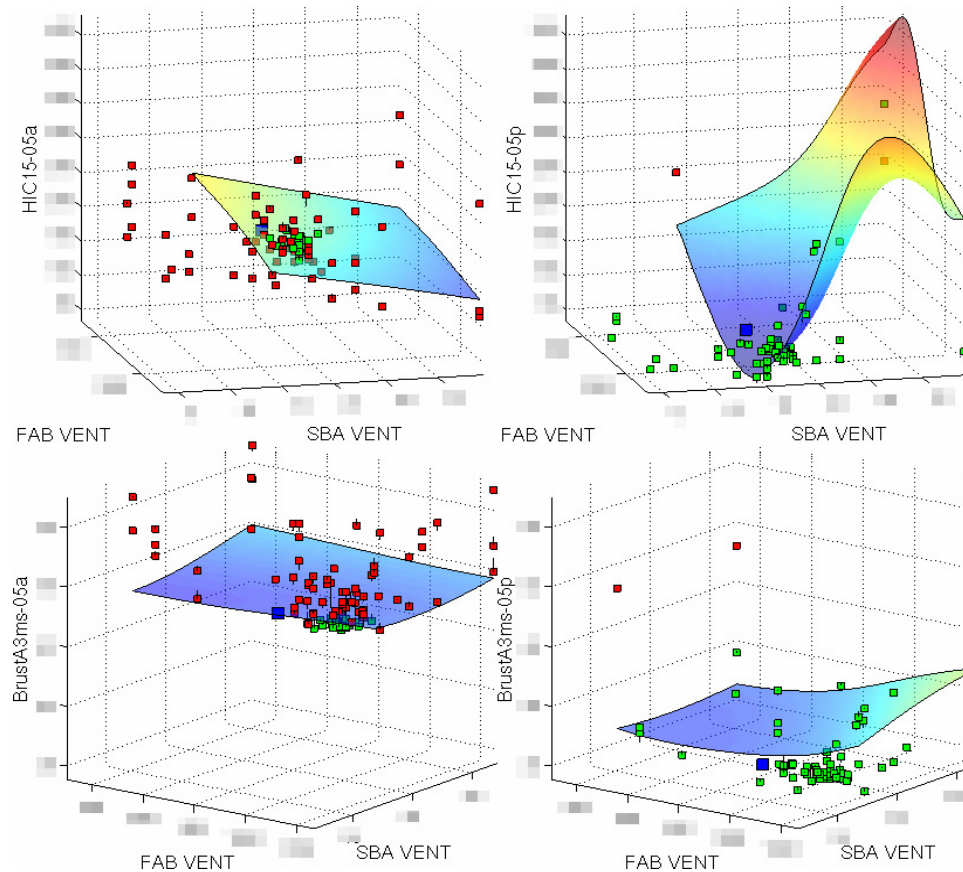
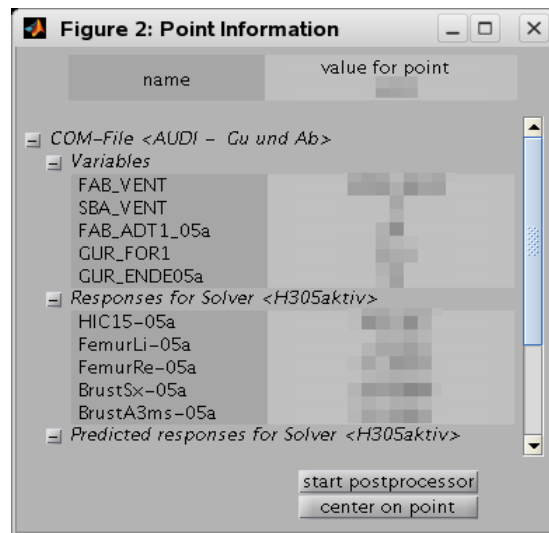
■ Thorax Acceleration

- > *BrustA3ms-05a*
- > *BrustA3ms-50a*
- > *BrustA3ms-05p*
- > *BrustA3ms-50p*



Optimization of an Adaptive Restraint System

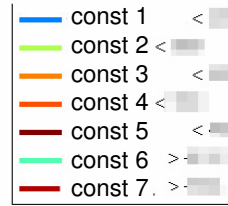
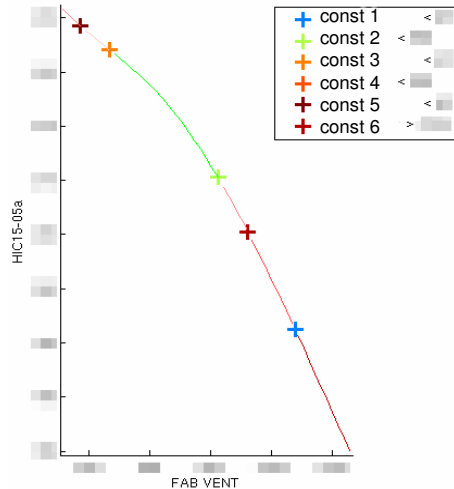
- § Meta-models for responses or composites
- § Analysis result points, residuals , optimum on meta-model
- § Point information



Optimization of an Adaptive Restraint System

§ Constraints:

- head injury coefficients (HIC)
- femur forces
- thorax intrusion
- thorax acceleration



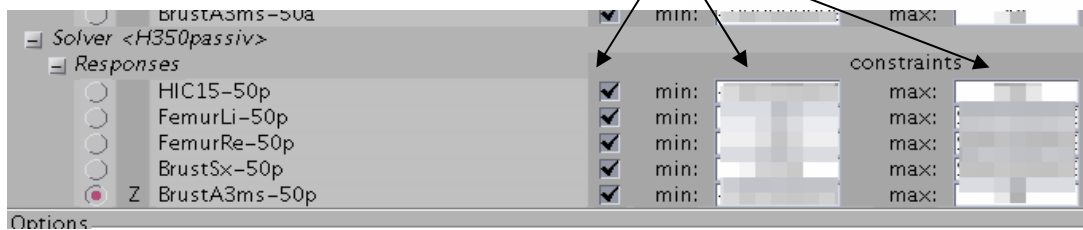
constraint
const 3
violated

constraints
const 3
and
const 5
violated

feasible

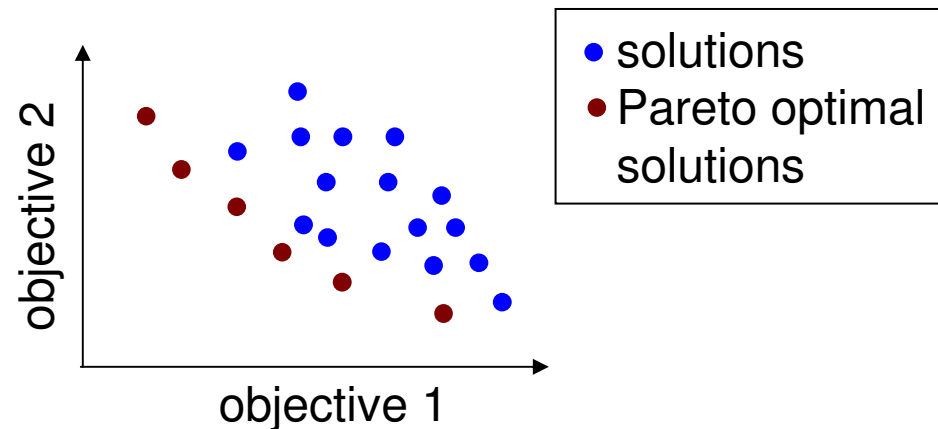
constraints may be
varied interactively

optimum on
response surface



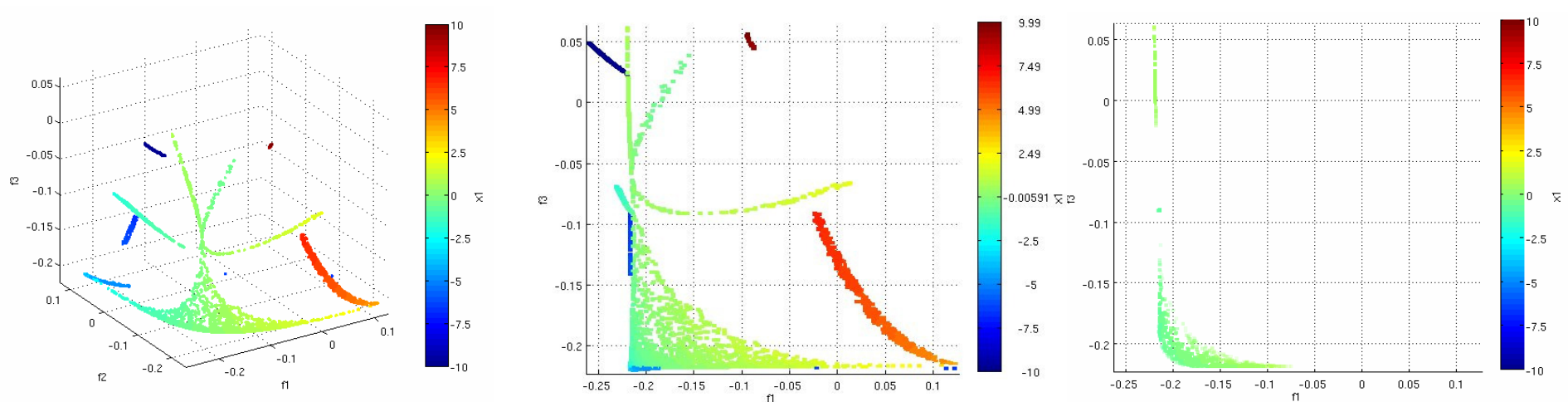
Optimization of an Adaptive Restraint System

- § Multi objective optimization
 - objectives often conflict (e.g. power and consumption of a vehicle)
 - no unique optimum
- § LS-OPT 3.3: capability to compute many Pareto optimal solution using genetic algorithm
- § Pareto optimal solution: no design provides better solutions for any objective without worsening another objective



Optimization of an Adaptive Restraint System

- § Visualization of Pareto Optimal solutions in D-SPEX
- 2D or 3D sections
 - color as additional dimension may be selected



- Pareto optimal solutions for 3 objectives
- color variable x_1

- 2D plot
- all points displayed

- 2D section
- objective f_2 set to fixed value

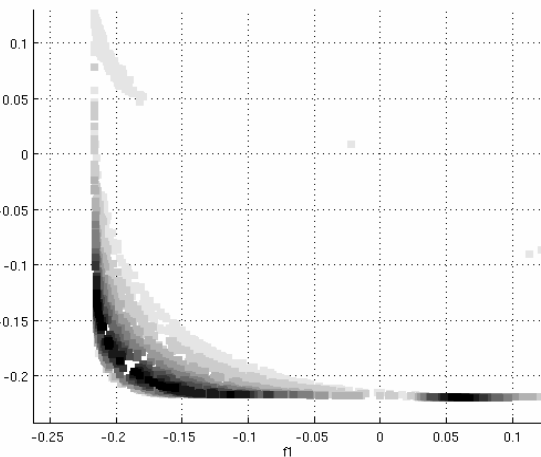
Optimization of an Adaptive Restraint System

- § All points or points within a small distance to the selected section may be plotted
- § Bandwidth may be selected by user
- § distance to the section is visualized using color-coding from black to white or transparency, if color is selected

The screenshot shows the DSPEX software interface. The main window is titled "DSPEX <trunk> - Settings for plot window <Plot Window #1>". It features a menu bar (File, Window, Task, Options) and several tabs (Single, Multi, Accuracy, History, Multi-History, Feasibility, Pareto, Expert). A "PLOT" button and a checked "instantly add" option are visible. Below the tabs is a table of objectives and variables. A red box highlights the "Responses" section, with a label "selected objectives" pointing to it. Another red box highlights the "value for fixed objective" field, with a label "value for fixed objective" pointing to it. A third red box highlights the "bandwidth of plotted points" field, with a label "bandwidth of plotted points" pointing to it. The "Options" section at the bottom includes "Range of response" (X, Y, Z, all axes) and "Plotting" options (iteration: #1, all previous iterations, tradeoff points, all points, points with distance < 10 % of design space).

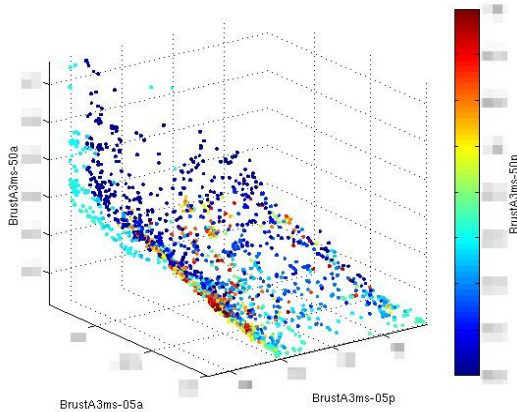
name	defined in solver	min
x1	x	
x2	x	
f1	objective	-0,25914
f2	objective	0,12287
f3	objective	-0,25

Options: Range of response (X, Y, Z, all axes), Plotting (iteration: #1, all previous iterations, tradeoff points, all points, points with distance < 10 % of design space)

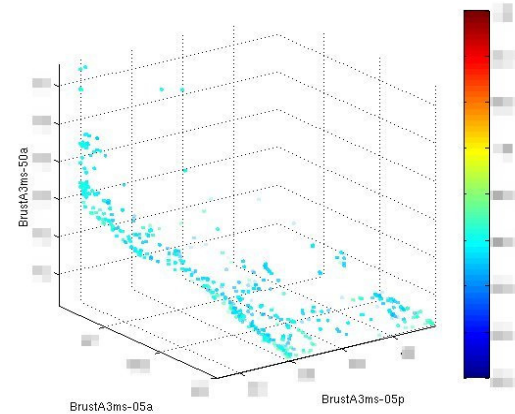


Optimization of an Adaptive Restraint System

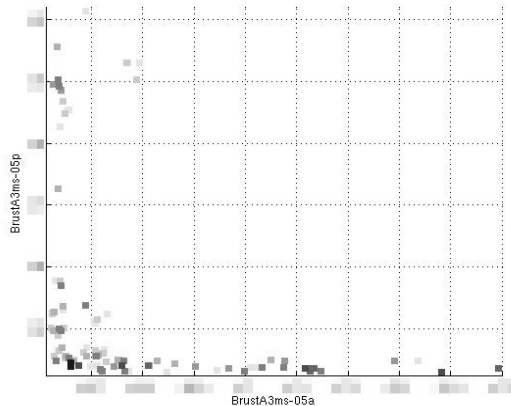
§ Pareto Optimal solutions



all Pareto optimal solutions



3D section, bandwidth 10% of design space

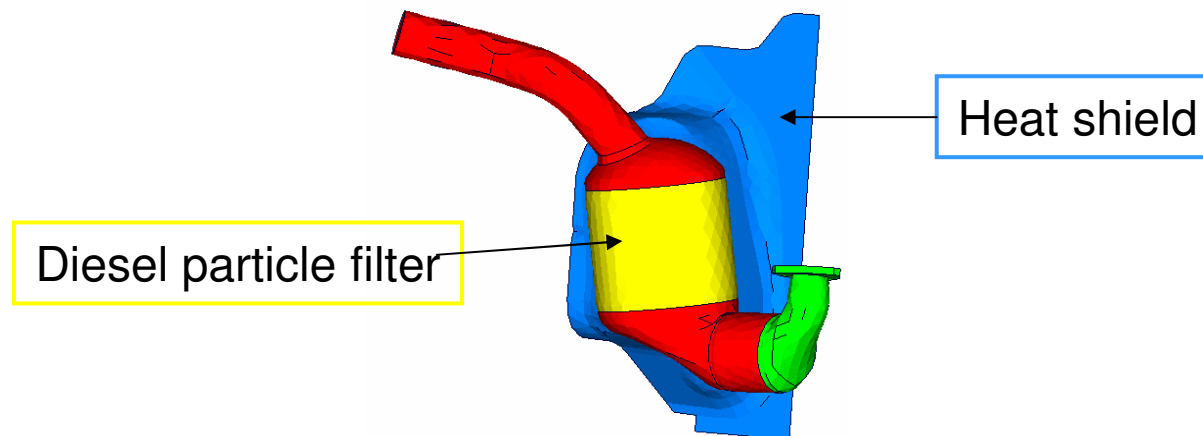


2D section, bandwidth 10% of design space

DOE Sensitivity Analysis with LS-OPT

§ Application Example: Radiation of a diesel particle filter

- Design variables:
 - materials of the heat shields
 - layer thicknesses of the heat shield
 - environment temperatures
 - temperature curve parameters of the heaters
- Constraints:
 - temperatures at some elements of the heat shield



DOE Sensitivity Analysis with LS-OPT

§ Feasibility Task

DSPEX Version <trunk>(revision 799) - Settings for plot window <Plot Window #1> <2>

File Window Task Options

Single Multi Anthill History Expert Feasibility

Feasibility information
This parameter constellation is **infeasible**

Parameter

name	value / feasibility
tumgebung	293.15 493.15 363.15
Verschiebung_WASB	0 0.05 0
temp_DPF_0	508.25 808.25 658.25
temp_DPF_max	518.25 818.25 668.36
temp_Trichter_Aus_end	499.36 799.36 640.5365

Solver <Dpf_Prostar_Gm_Poly>

Responses

name	min	max	soft	value
max_WASB_3600_innen	-99999999	480	soft	406.9129
max_WASB_2677_innen	-99999999	480	soft	369.417
max_WASB_2887_innen	-99999999	480	soft	434.5013
max_WASB_3600_aussen	-99999999	450	soft	365.9023
max_WASB_2677_aussen	-99999999	450	soft	365.196
max_WASB_2887_aussen	-99999999	450	soft	367.7667

Composites

name	min	max	soft	value
constraint_alu	0	999999999	soft	0
constraint_stahl	0	999999999	soft	0
constraint_temp_DPF	0	999999999	soft	10.11
constraint_temp_Kruemmer	0	999999999	soft	5
constraint_temp_Trichter_Aus	0	999999999	soft	-45.0365
constraint_temp_Trichter_Ein	0	999999999	soft	16.86
constraint_temp_Vorkat	0	999999999	soft	66.13

DSPEX Version <trunk>(revision 799) - Settings for plot window <Plot Window #1> <2>

File Window Task Options

Single Multi Anthill History Expert Feasibility

Feasibility information
This parameter constellation is **feasible**

Parameter

name	value / feasibility
tumgebung	293.15 493.15 363.15
Verschiebung_WASB	0 0.05 0
temp_DPF_0	508.25 808.25 658.25
temp_DPF_max	518.25 818.25 668.36
temp_Trichter_Aus_end	499.36 799.36 640.5365

Responses

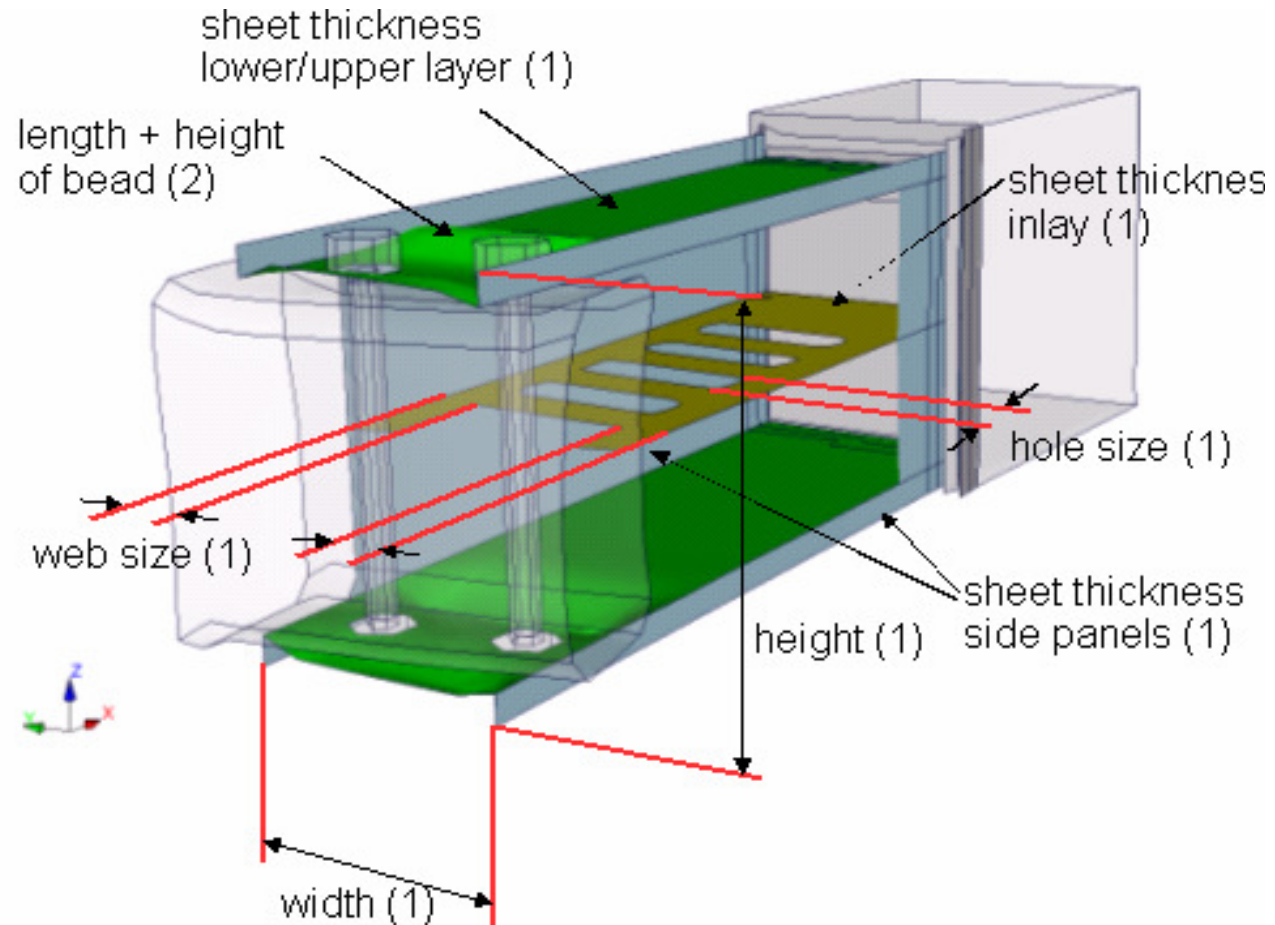
name	min	max	soft	value
max_WASB_3600_innen	-99999999	480	soft	405.6338
max_WASB_2677_innen	-99999999	480	soft	367.974
max_WASB_2887_innen	-99999999	480	soft	434.2103
max_WASB_3600_aussen	-99999999	450	soft	367.1681
max_WASB_2677_aussen	-99999999	450	soft	366.4466
max_WASB_2887_aussen	-99999999	450	soft	369.1395

Composites

name	min	max	soft	value
constraint_alu	0	999999999	soft	0
constraint_stahl	0	999999999	soft	0
constraint_temp_DPF	0	999999999	soft	10.11
constraint_temp_Kruemmer	0	999999999	soft	5
constraint_temp_Trichter_Aus	0	999999999	soft	16.7282
constraint_temp_Trichter_Ein	0	999999999	soft	16.86
constraint_temp_Vorkat	0	999999999	soft	66.13

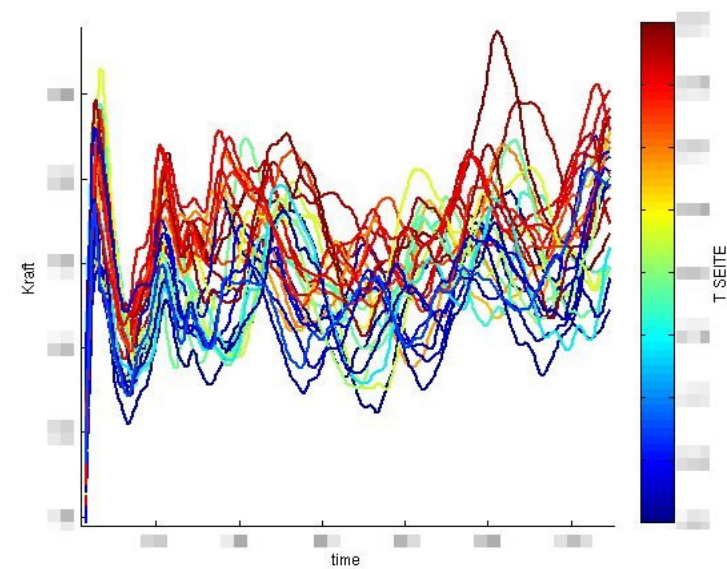
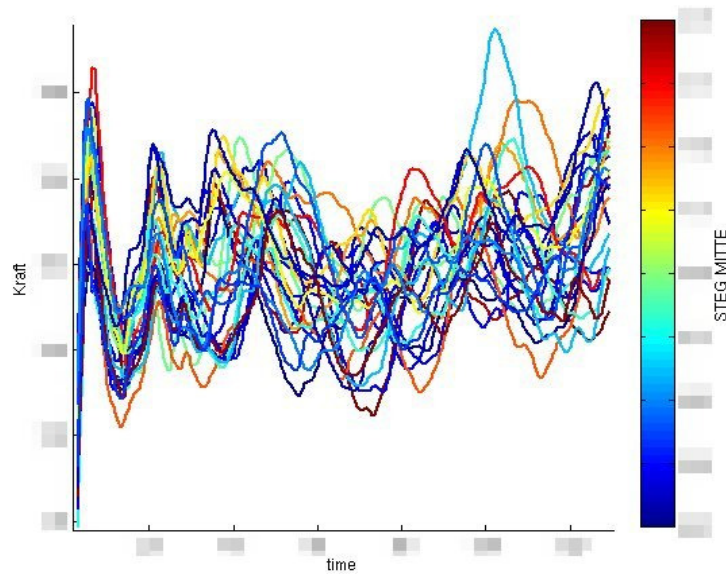
Application of Shape Optimization with LS-OPT

- § Improvement of the energy absorption of a crash box for a reduced maximum force level



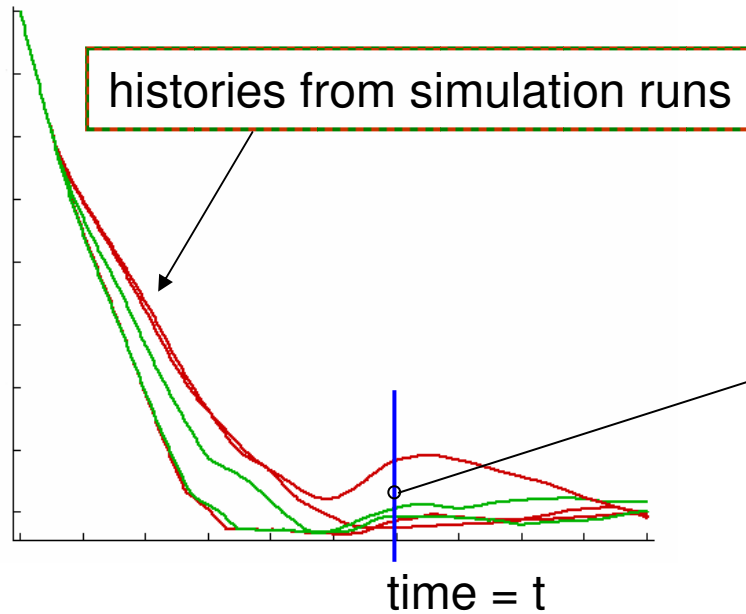
Application of Shape Optimization with LS-OPT

- § History curves
- § Color of the curves to display the respective value of a variable, response or composite

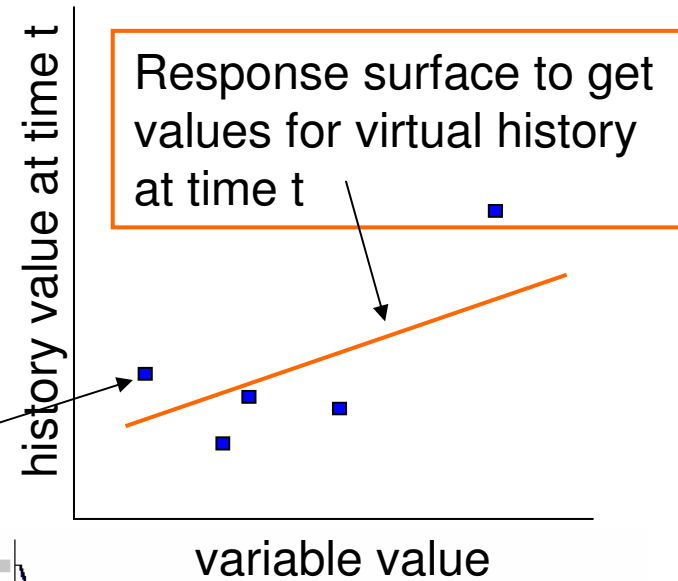


DOE Sensitivity Analysis with LS-OPT

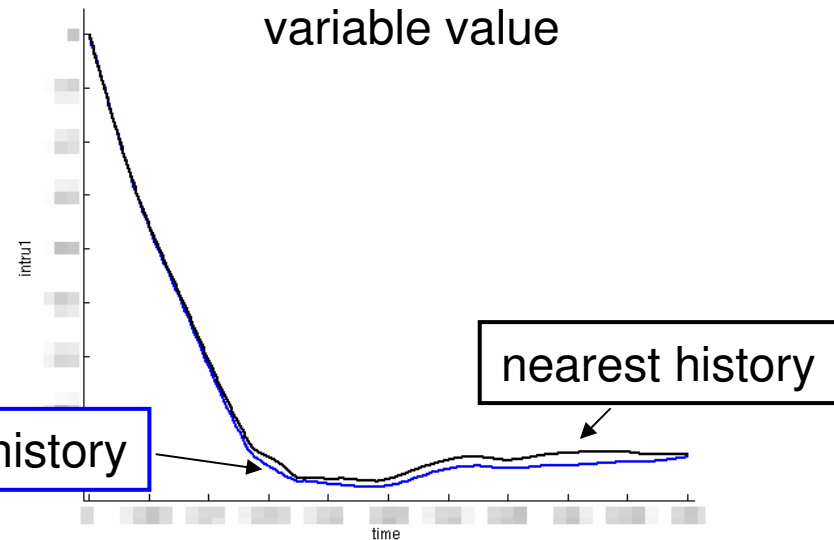
§ Calculation of virtual histories



calculation for equidistant time values
↳ virtual history



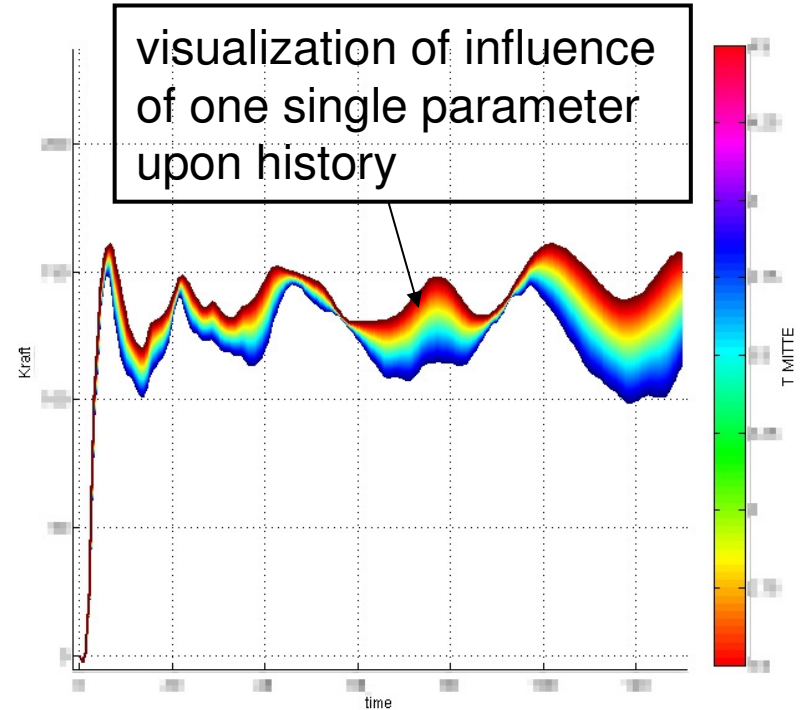
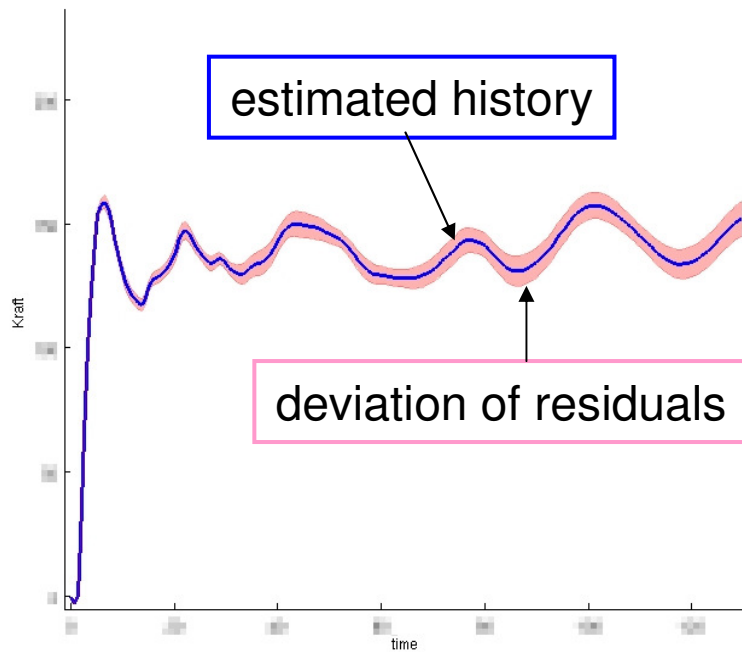
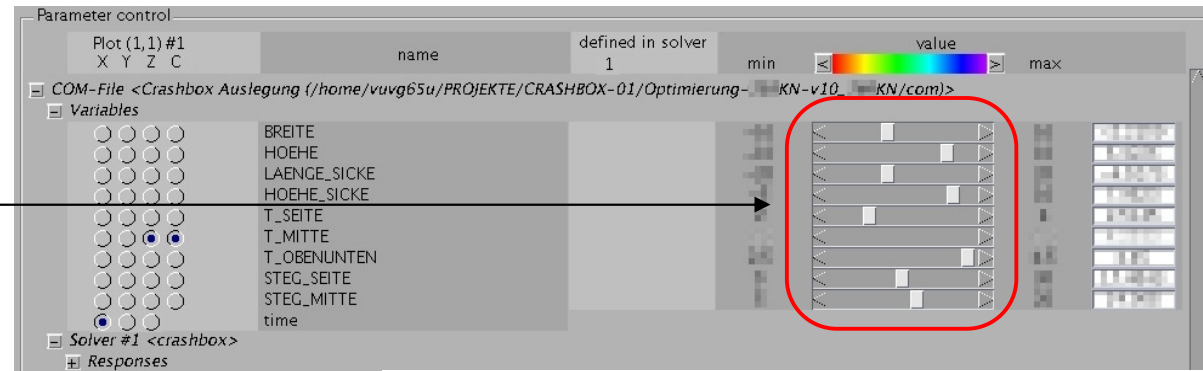
virtual history



Application of Shape Optimization with LS-OPT

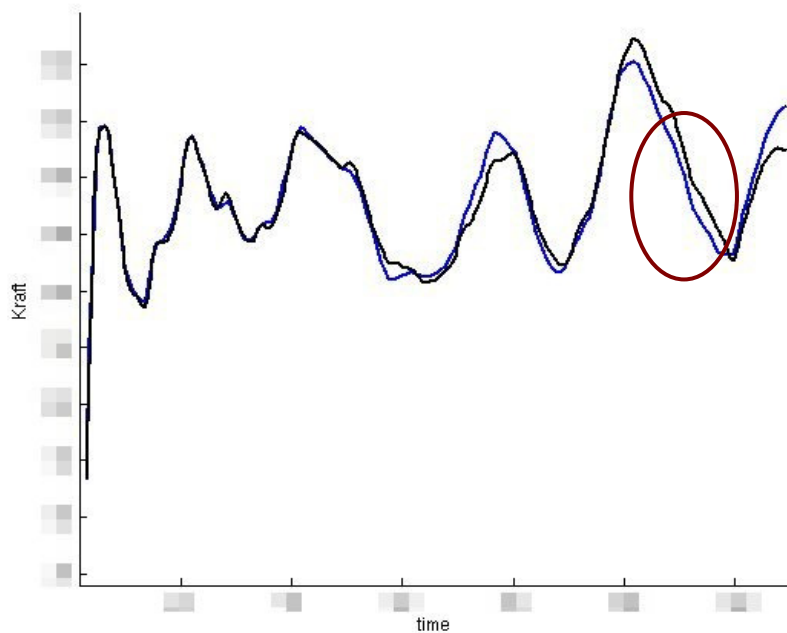
§ Virtual Histories

slider to select parameter constellation

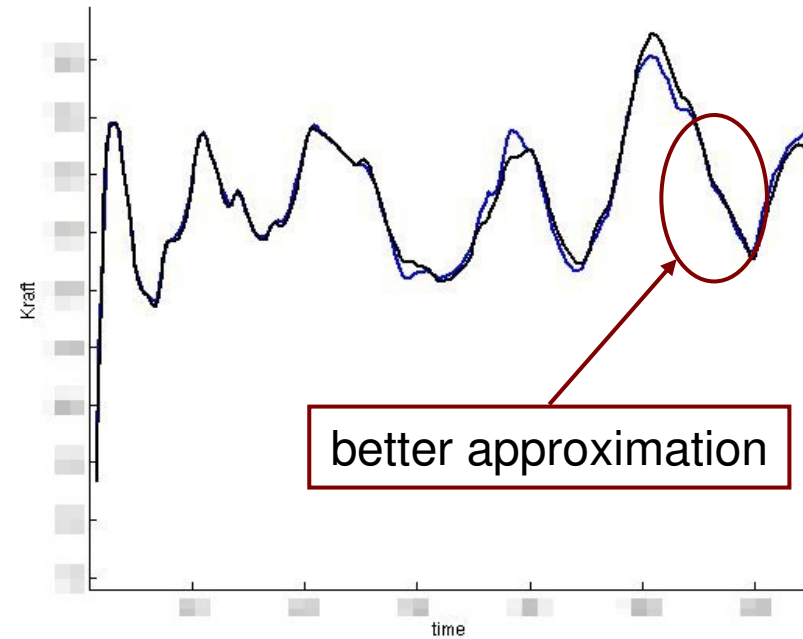


Application of Shape Optimization with LS-OPT

§ Comparison of different meta-model types

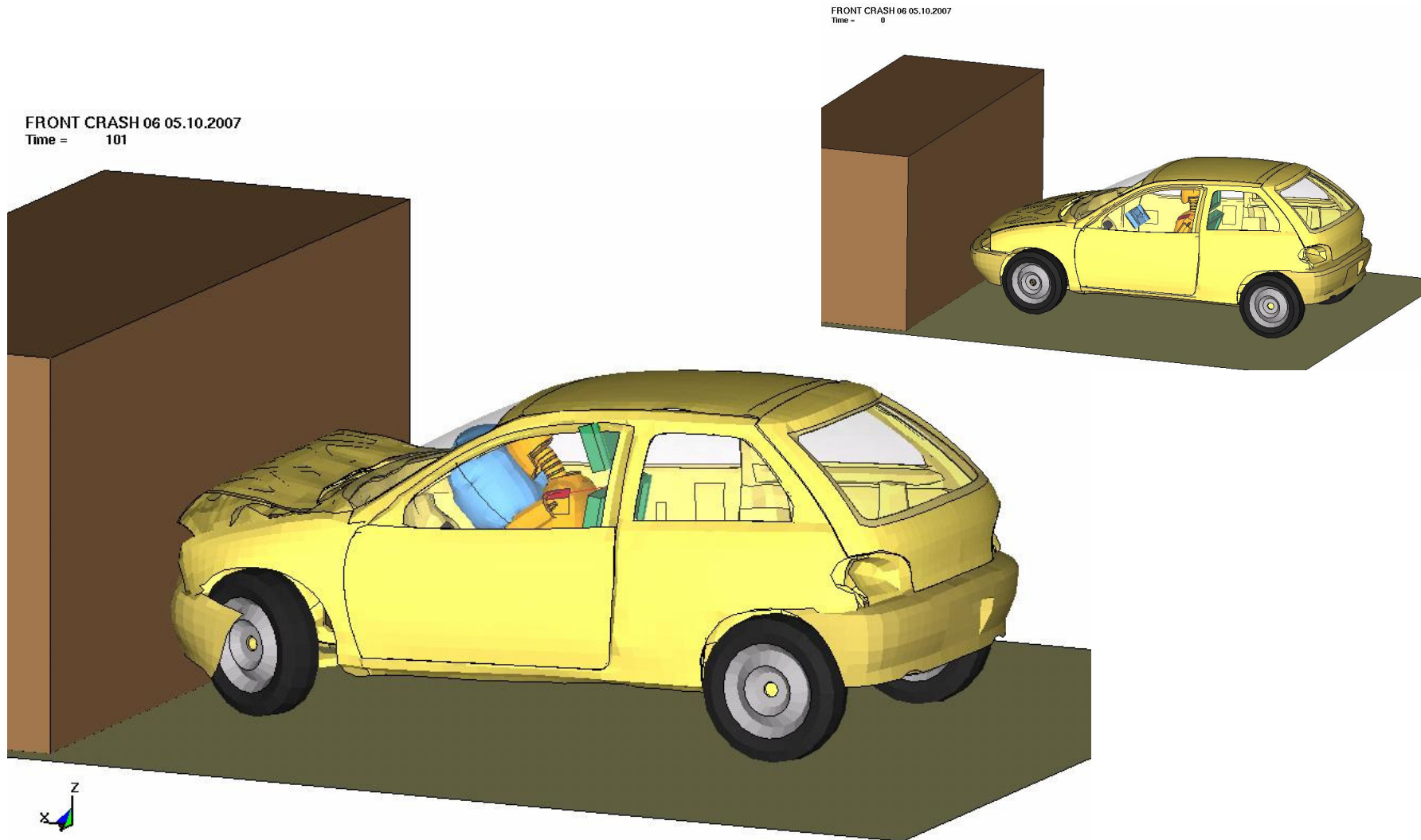


Linear approximation



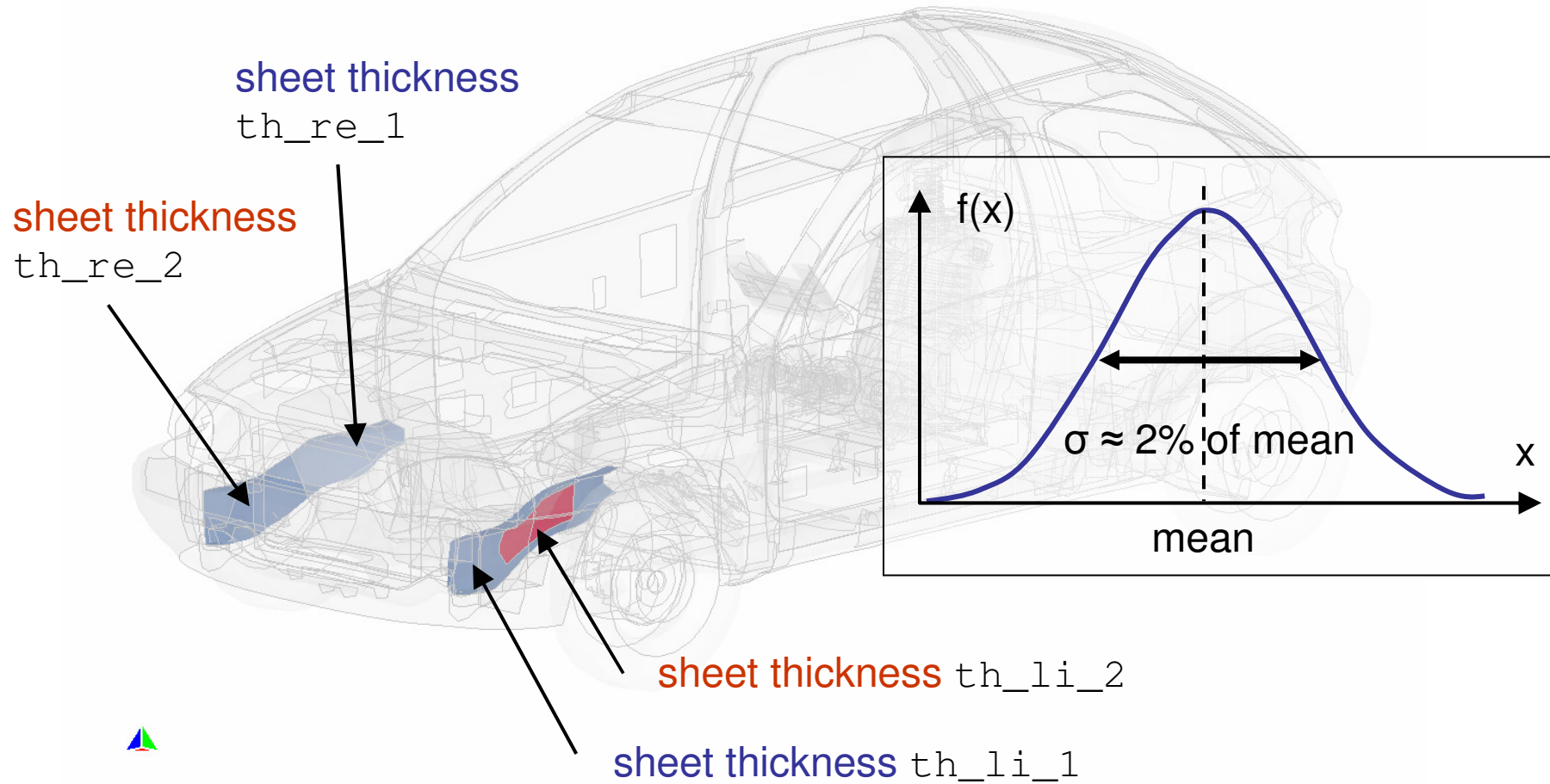
Moving least squares approximation

Stochastic Analysis – Front-Crash

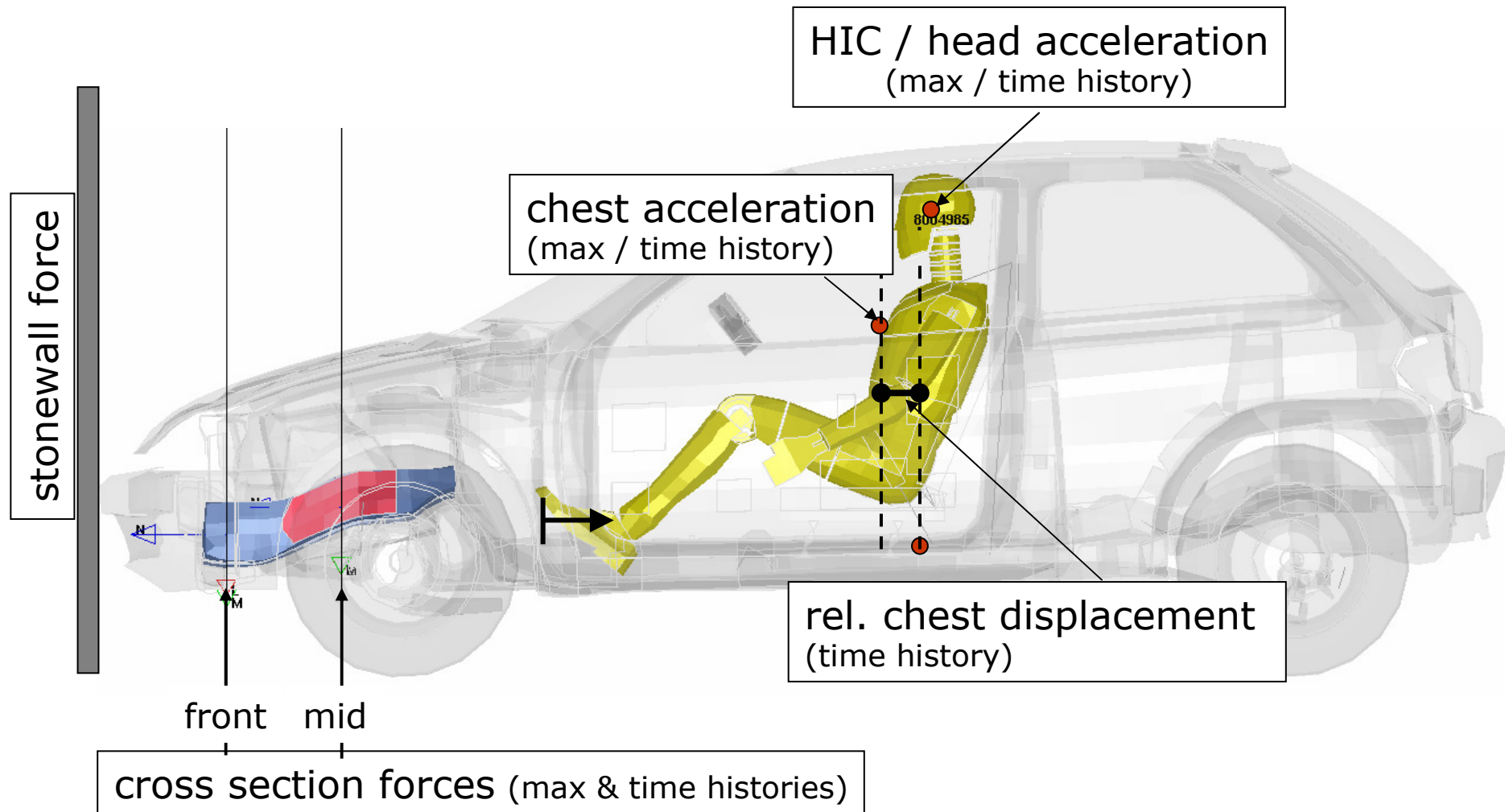


Stochastic Analysis – Front-Crash

Stochastic parameters



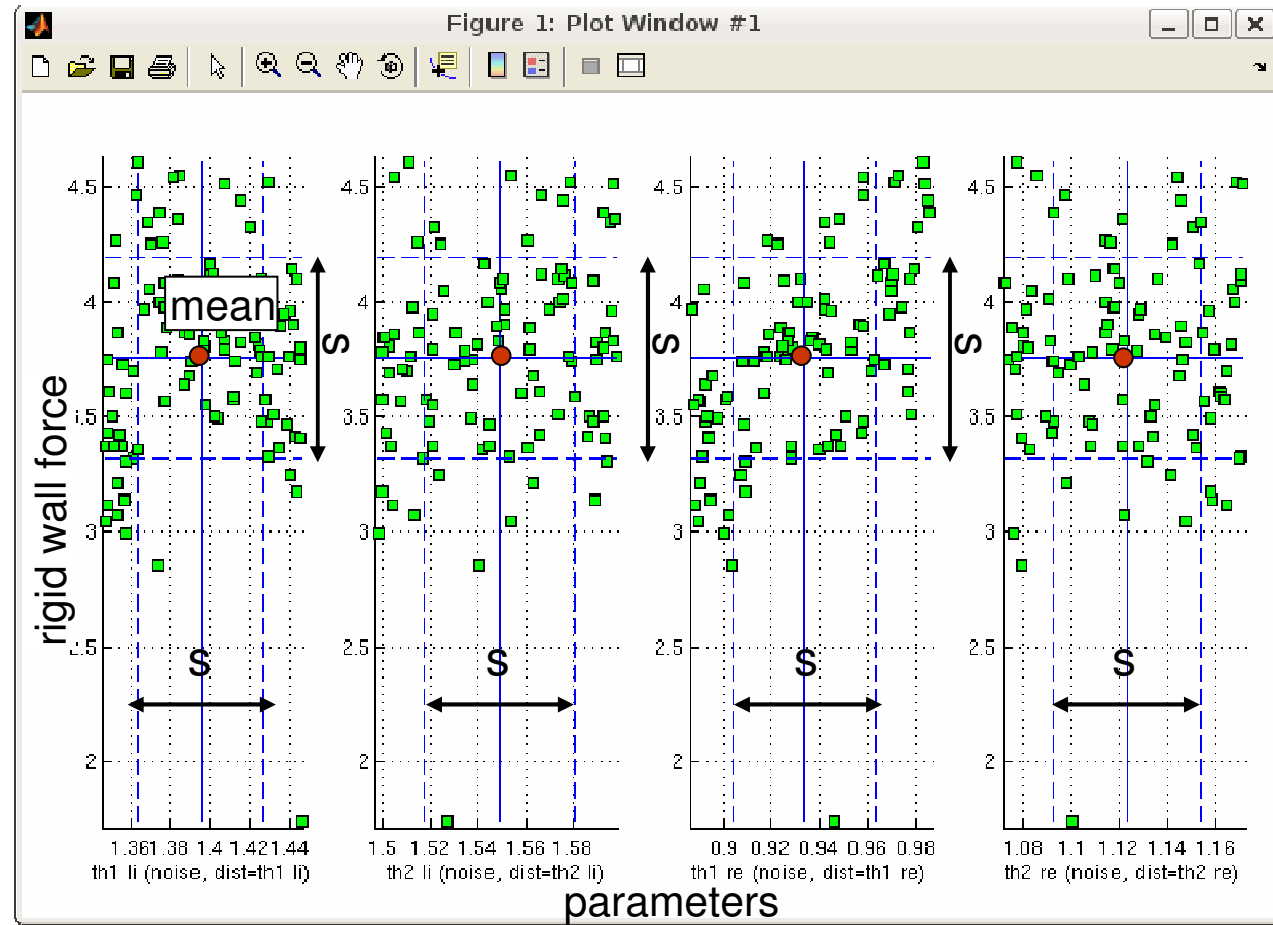
Stochastic Analysis – Front-Crash



Stochastic Analysis – Front-Crash

Statistics / Plots

- § anthill plots
- § mean value
- § standard deviations
- § marked points



Stochastic Analysis – Front-Crash

Probability distribution type / empirical distribution

Visualization of ...

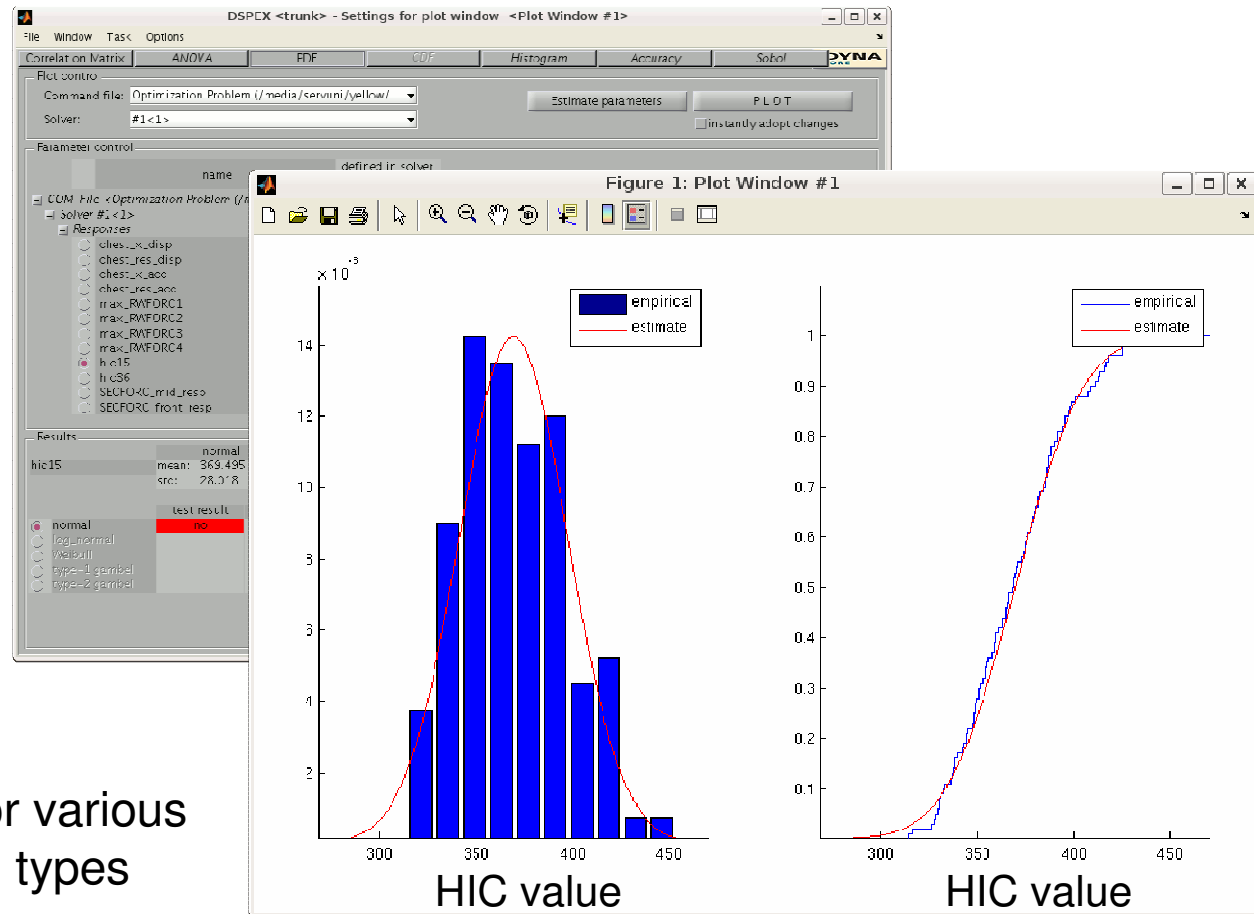
§ PDF

§ CDF
(both empirical
and estimated)

§ histogram

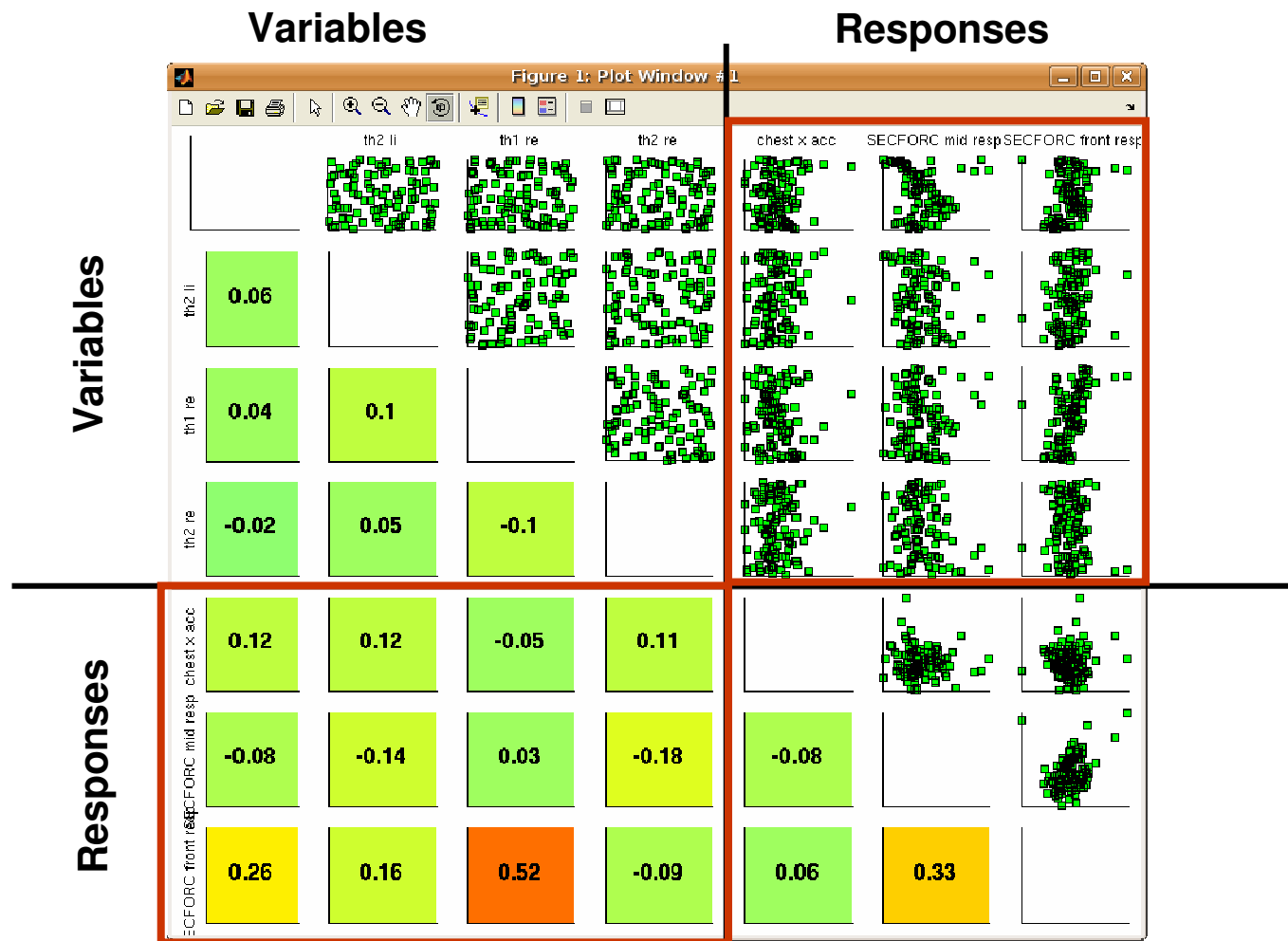
Statistical test (K-S)

§ goodness of fit test for various
probability distribution types



Stochastic Analysis – Front-Crash

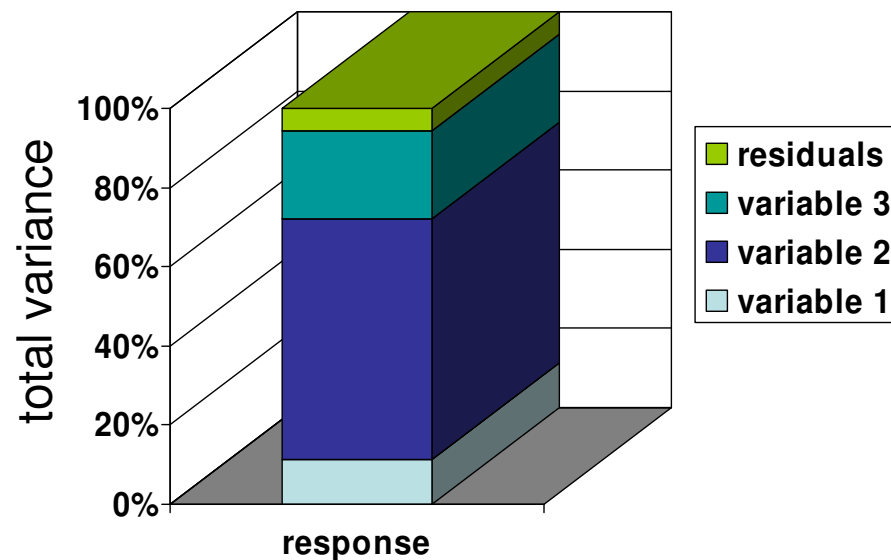
Statistics / linear Sensitivity: Correlation matrix



Stochastic Analysis – Front-Crash

Approaches:

- § regression-based methods (e.g. correlation coefficient)
- § variance-based methods:
 - § linear ANOVA (Fisher et al.)
 - § **Sobol' indices**
generally applicable non-linear sensitivity measure



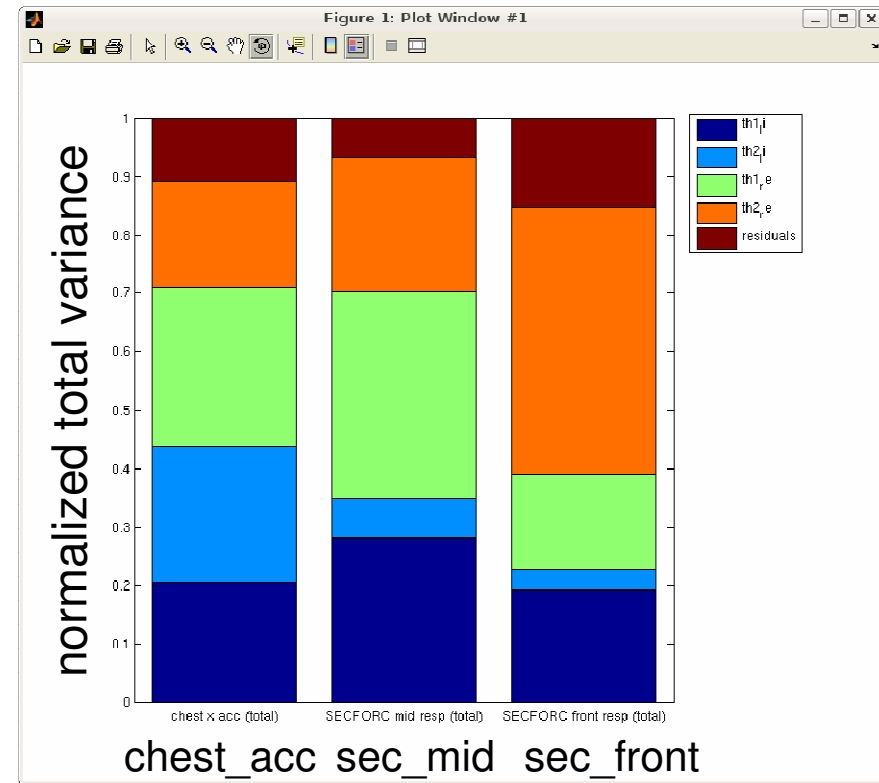
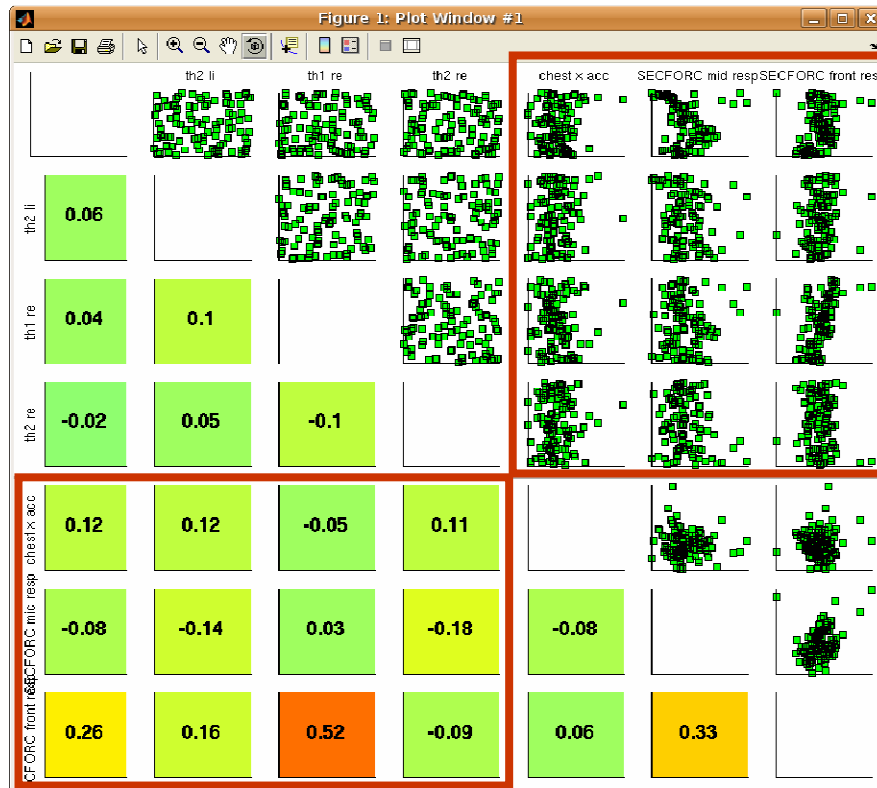
Sobol' indice of variable v_i

$$S_i = \frac{\text{variance caused due to } v_i}{\text{total variance of response}}$$

determination computational
expensive ▶ meta models are applied

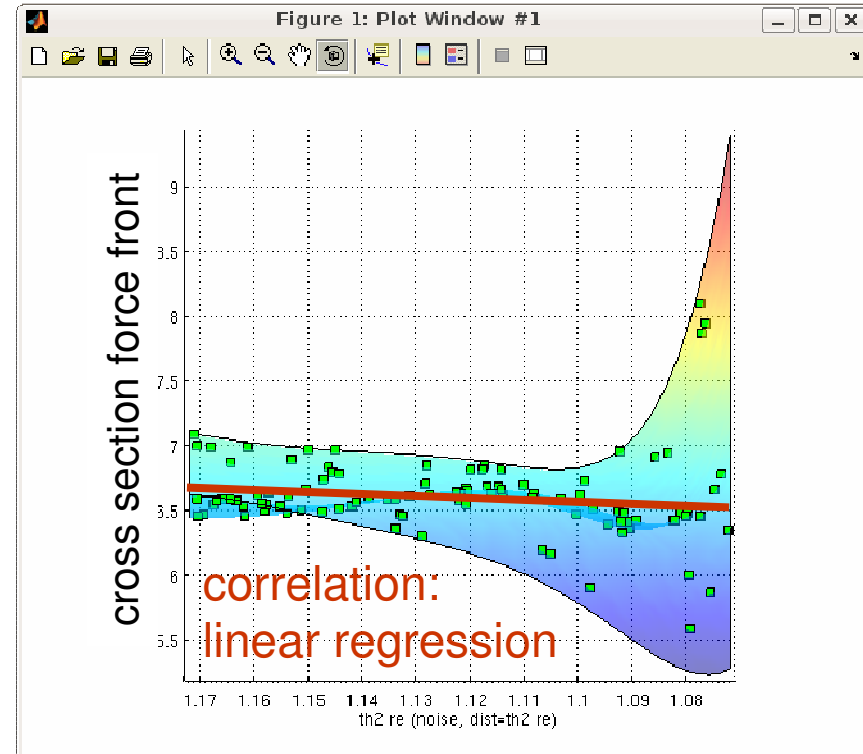
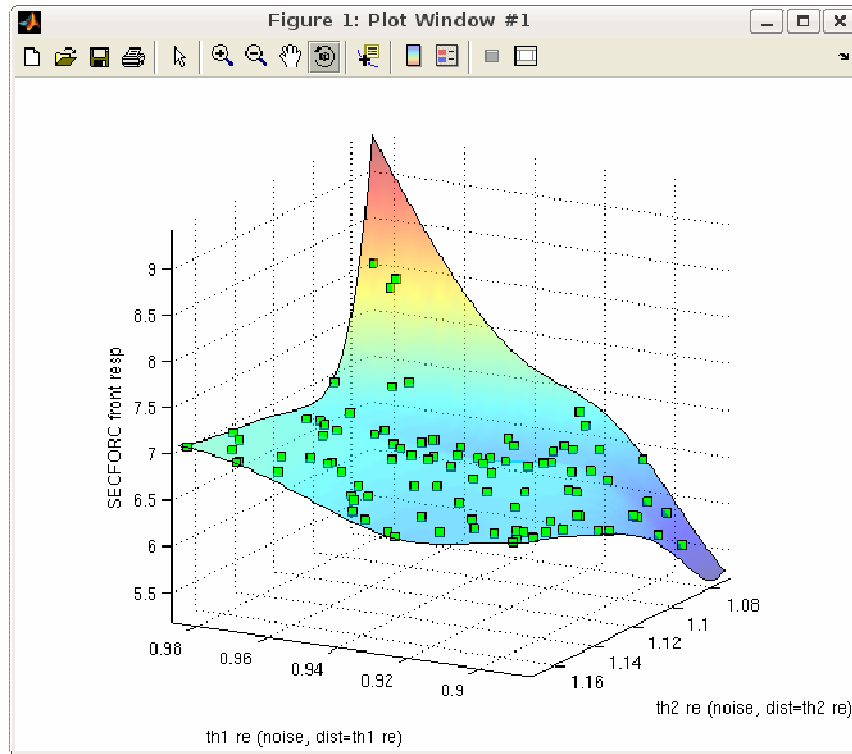
Stochastic Analysis – Front-Crash

linear vs. non-linear Sensitivity: Sobol' indices / Correlation



Stochastic Analysis – Front-Crash

Meta model visualization



Conclusions

- § D-SPEX has been started as a prototype and testing environment for features
- § D-SPEX is now an outgrown product that is used in a production environment
- § D-SPEX provides a set of features that are unique for its kind of software
- § The visualization of constraints has been proven to be invaluable to explain the optimal results especially for multi load case optimizations or multi disciplinary optimizations
- § The visualization of “virtual histories” gives the engineer a new perspective
- ⌚ D-SPEX is meant to be a tool that supports the engineer in the process of understanding their system behavior