D-SPEX

an advanced post-processor for optimization and stochastic investigations

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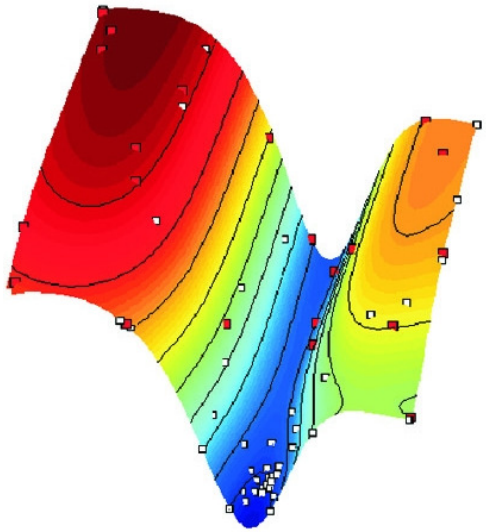


Overview

- 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

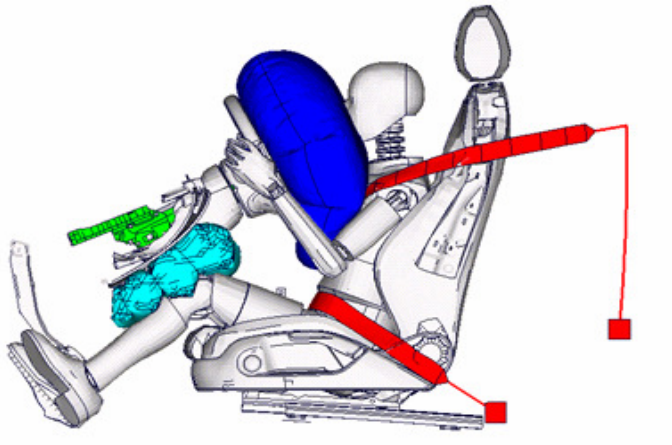
Optimization of a Adaptive Restraint System

§ **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**:

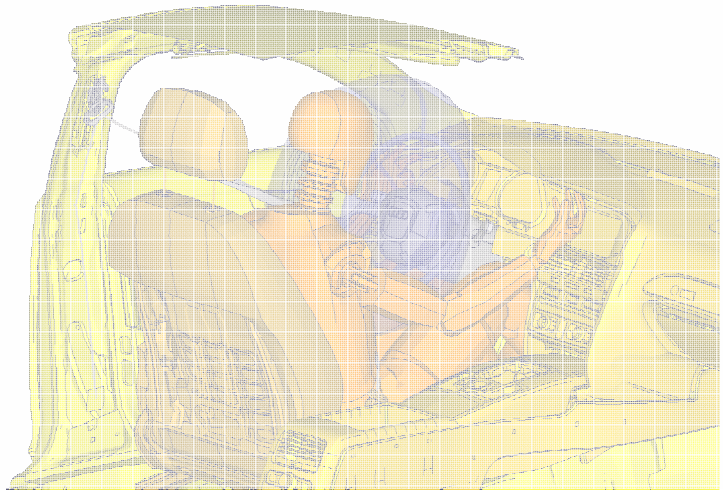
- upper force level
- the area of the vent holes
- trigger times of restraint system



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

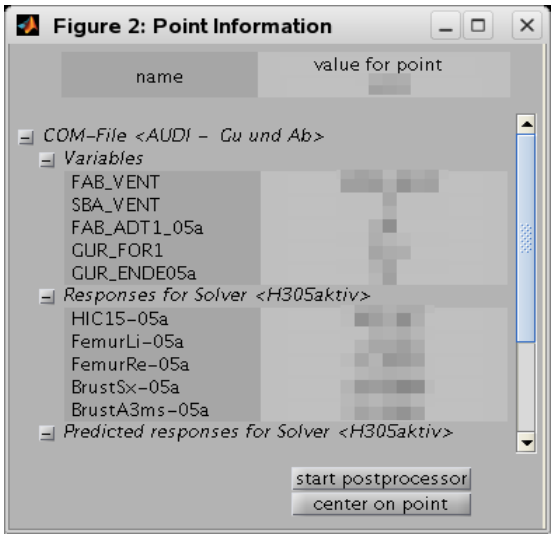
```
-> BrustSx-05a
-> BrustSx-50a
-> BrustSx-05p
-> BrustSx-50p
```

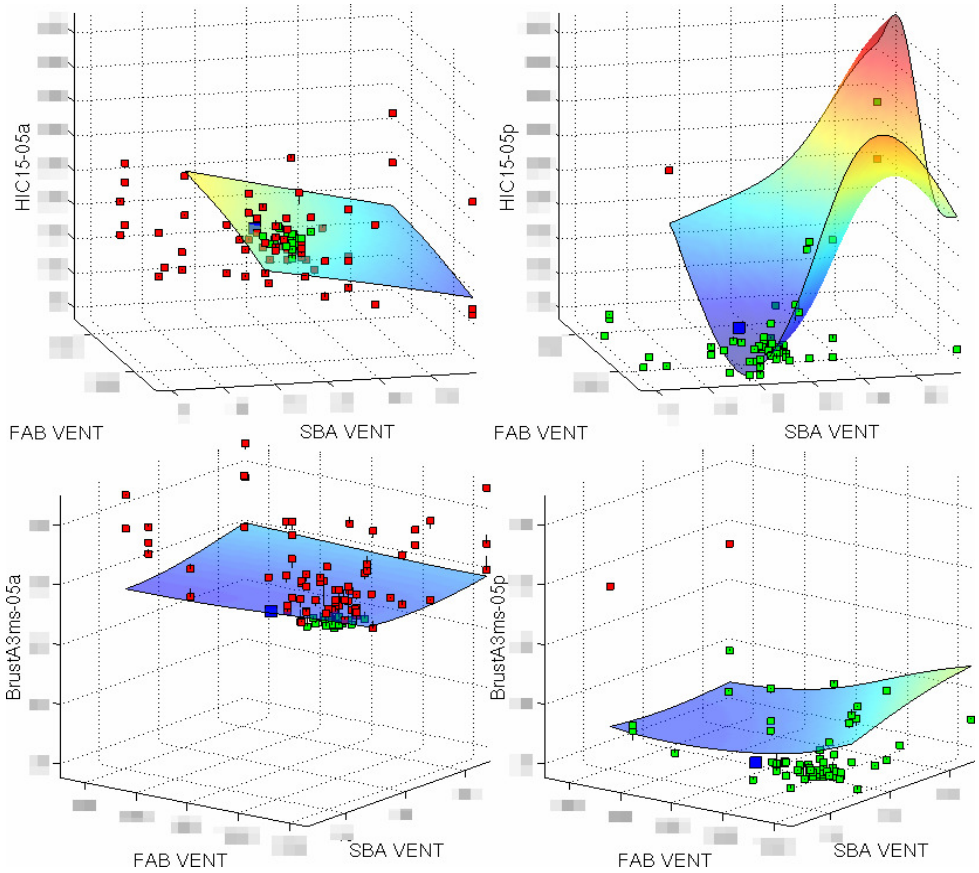
  - Thorax Acceleration

```
-> BrustA3ms-05a
-> BrustA3ms-50a
-> BrustA3ms-05p
-> BrustA3ms-50p
```

Optimization of an Adaptive Restraint System

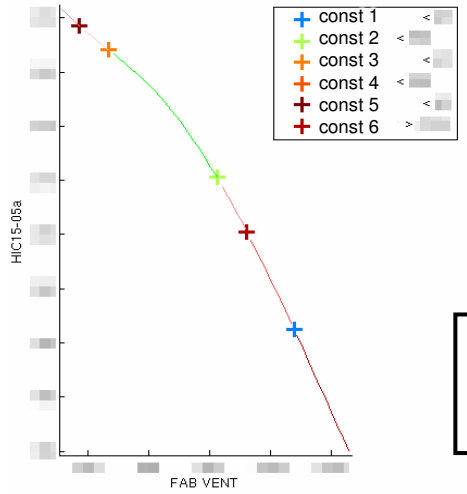
- Meta-models for responses or composites
- Analysis result points, residuals , optimum on meta-model
- Point information





Optimization of an Adaptive Restraint System

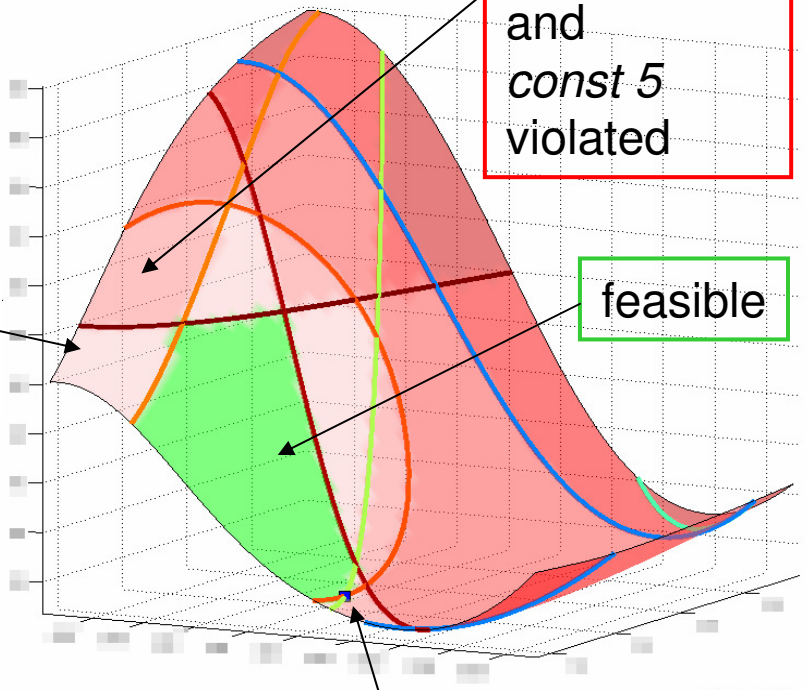
- Constraints:
  - head injury coefficients (HIC)
  - femur forces
  - thorax intrusion
  - thorax acceleration



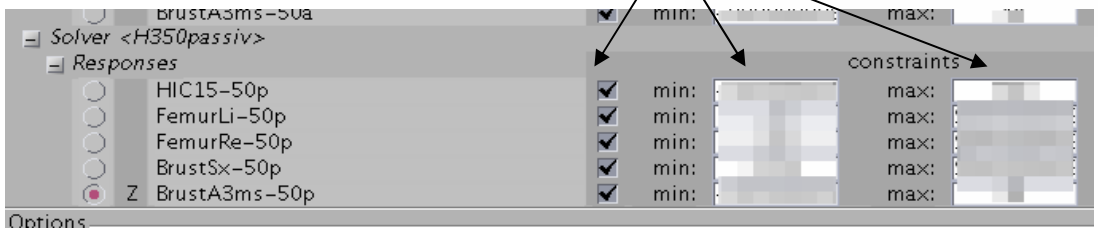
constraint *const 3* violated

constraints *const 3* and *const 5* violated

feasible



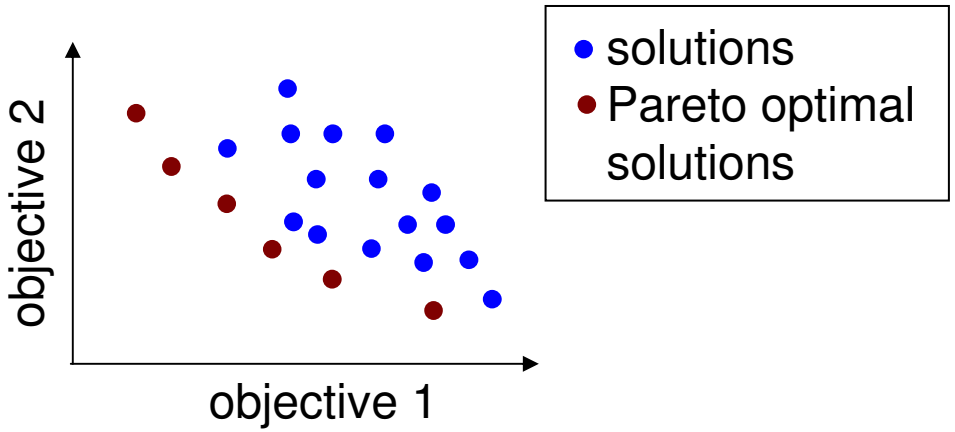
constraints may be varied interactively



optimum on response surface

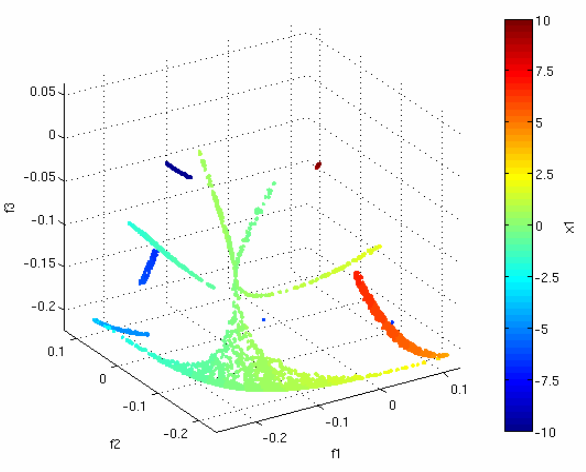
Optimization of an Adaptive Restraint System

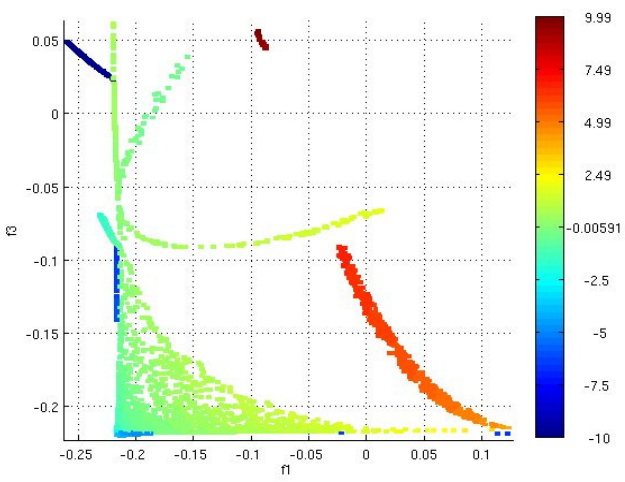
- Multi objective optimization
  - objectives often conflict (e.g. power and consumption of a vehicle)
  - no unique optimum
- LS-OPT 3.3: capability to compute many Pareto optimal solution using genetic algorithm
- Pareto optimal solution: no design provides better solutions for any objective without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

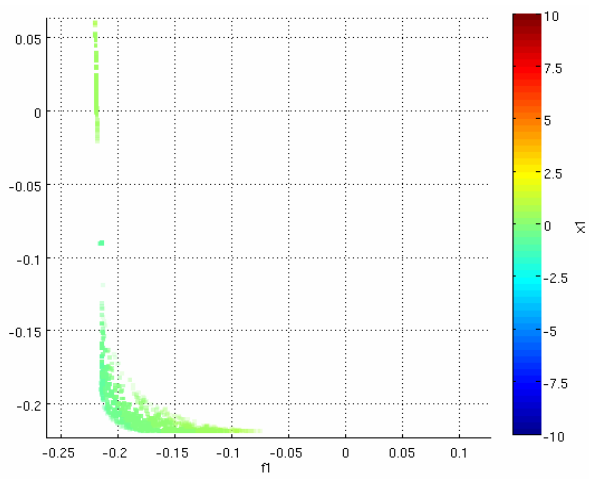


Optimization of an Adaptive Restraint System

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







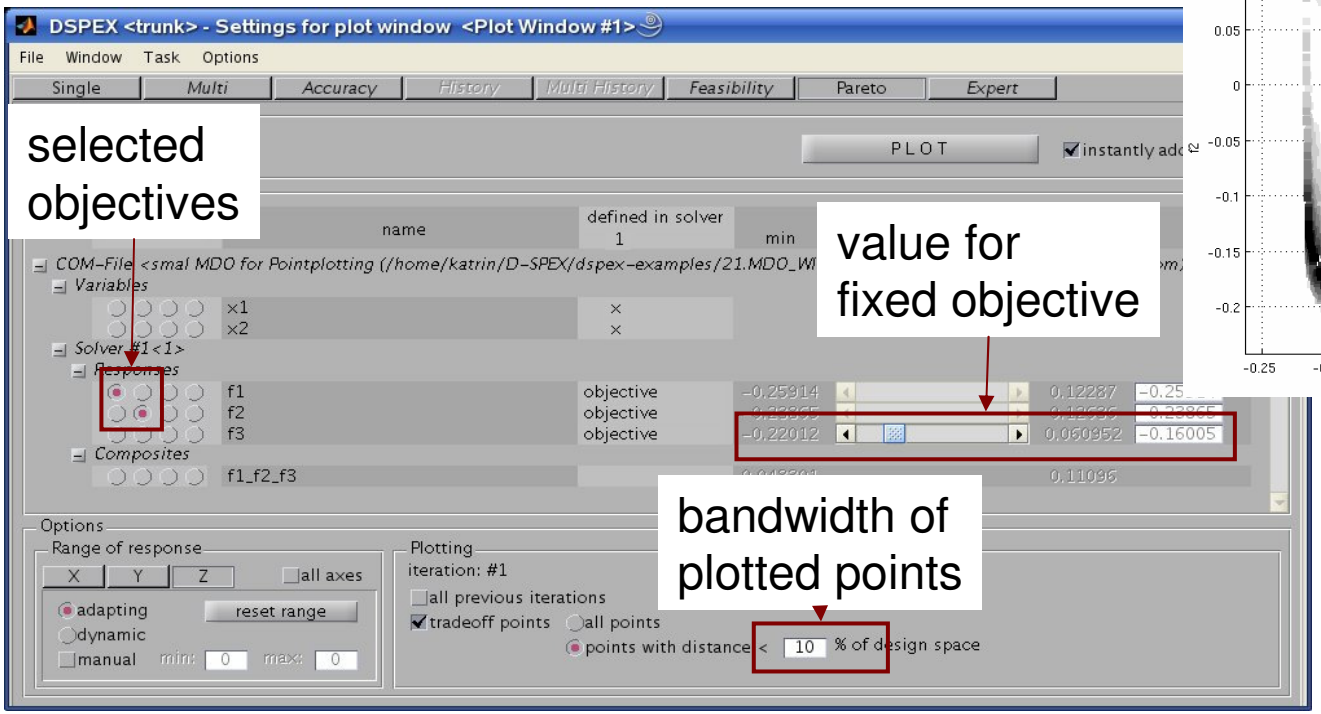
- Pareto optimal solutions for 3 objectives
- color variable x1

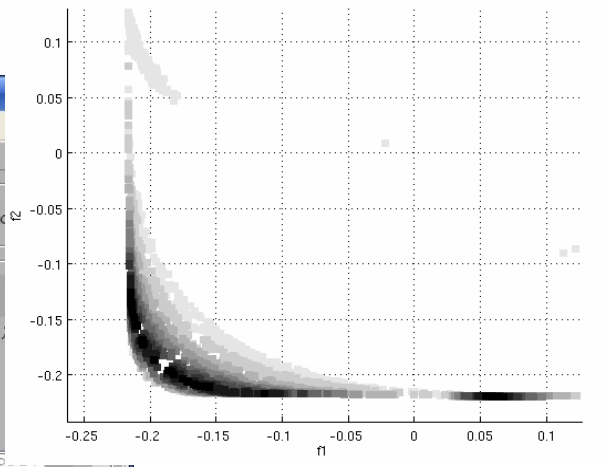
- 2D plot
- all points displayed

- 2D section
- objective f2 set to fixed value

Optimization of an Adaptive Restraint System

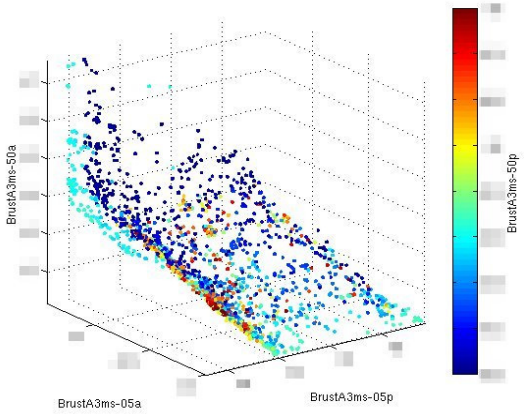
- All points or points within a small distance to the selected section may be plotted
- Bandwidth may be selected by user
- distance to the section is visualized using color-coding from black to white or transparency, if color is selected



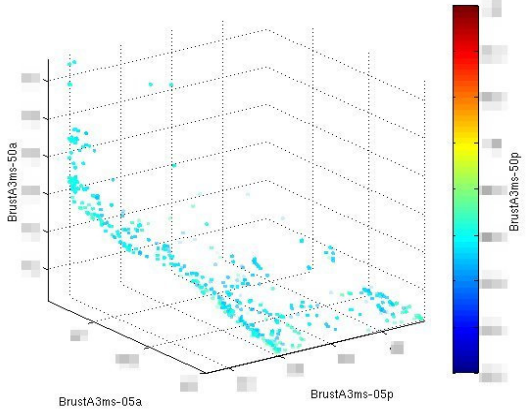


Optimization of an Adaptive Restraint System

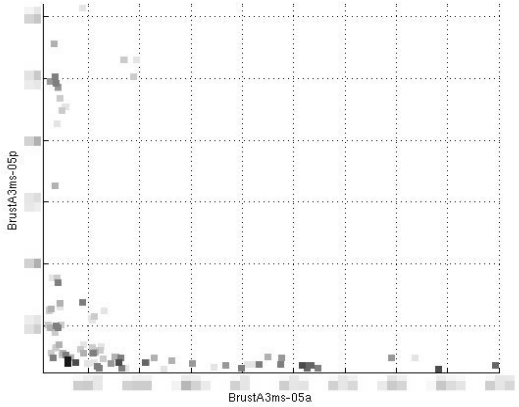
§ Pareto Optimal solutions



all Pareto optimal solutions



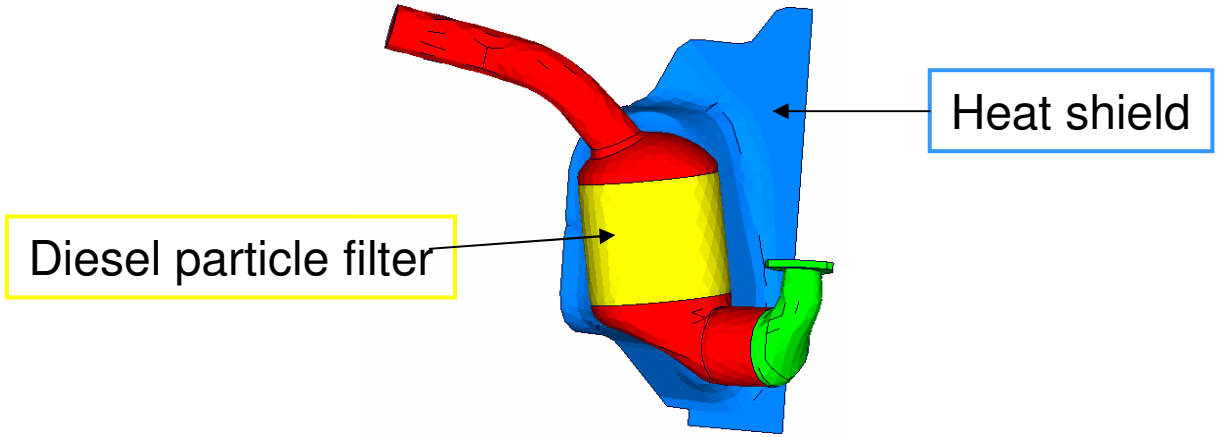
3D section, bandwidth 10% of design space



2D section, bandwidth 10% of design space

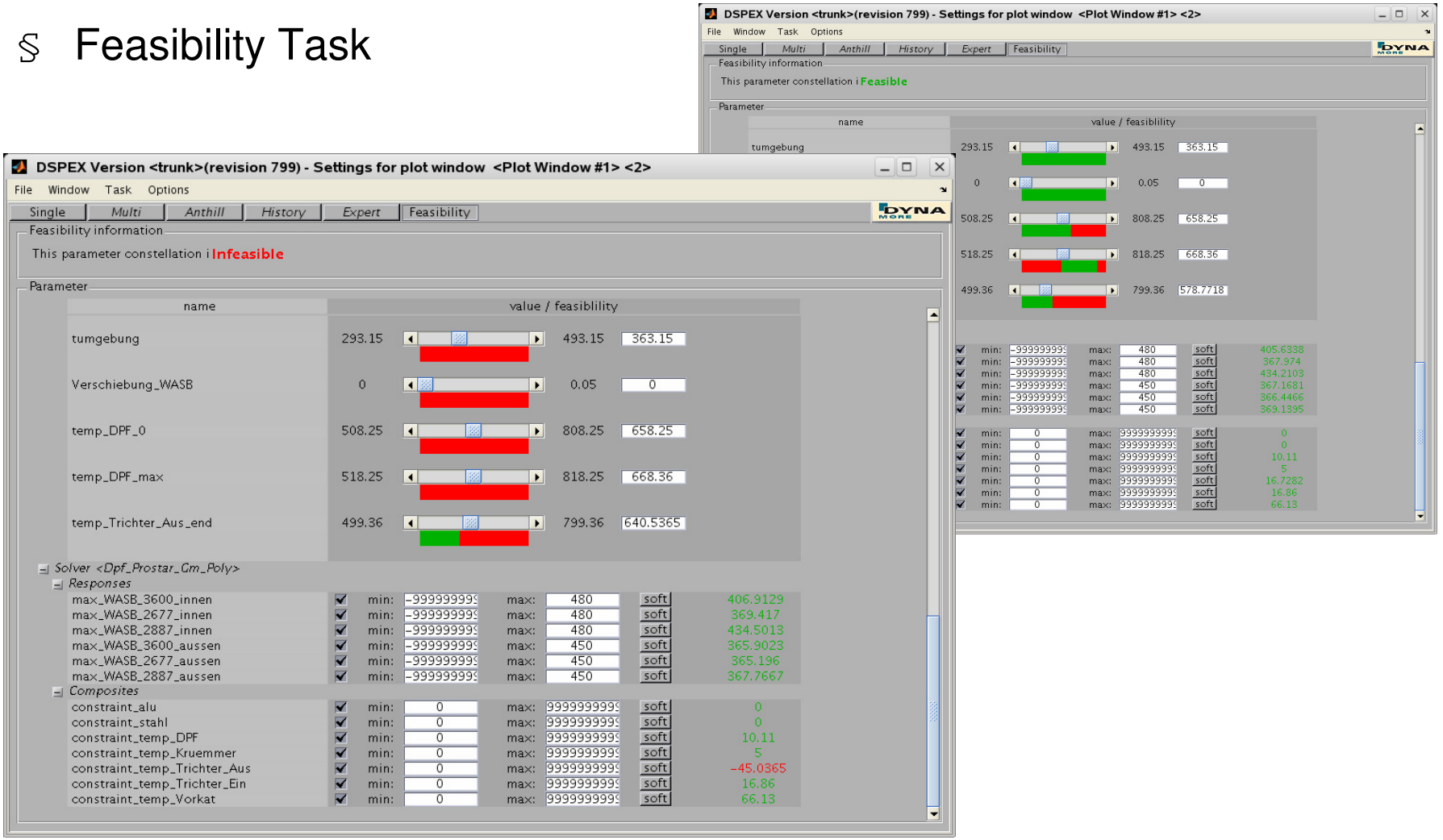
DOE Sensitivity Analysis with LS-OPT

- 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



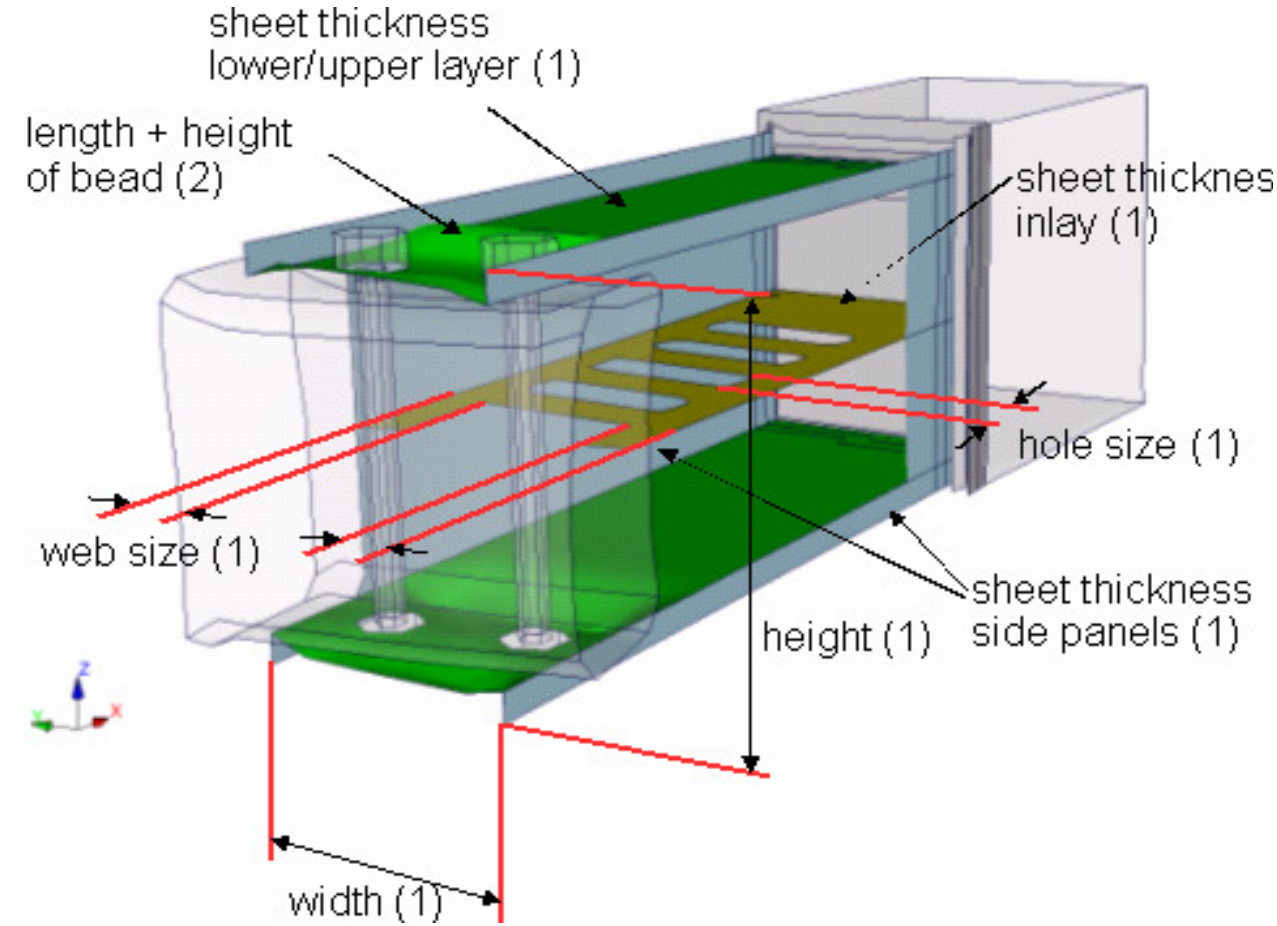
DOE Sensitivity Analysis with LS-OPT

- Feasibility Task



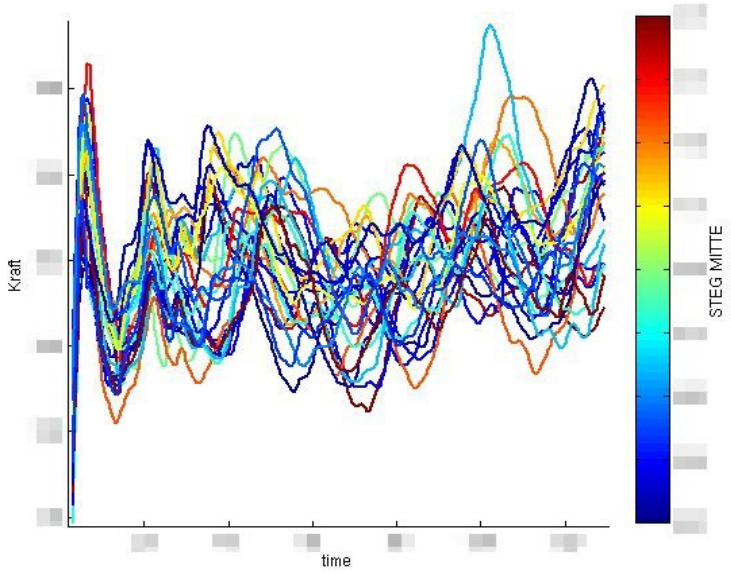
Application of Shape Optimization with LS-OPT

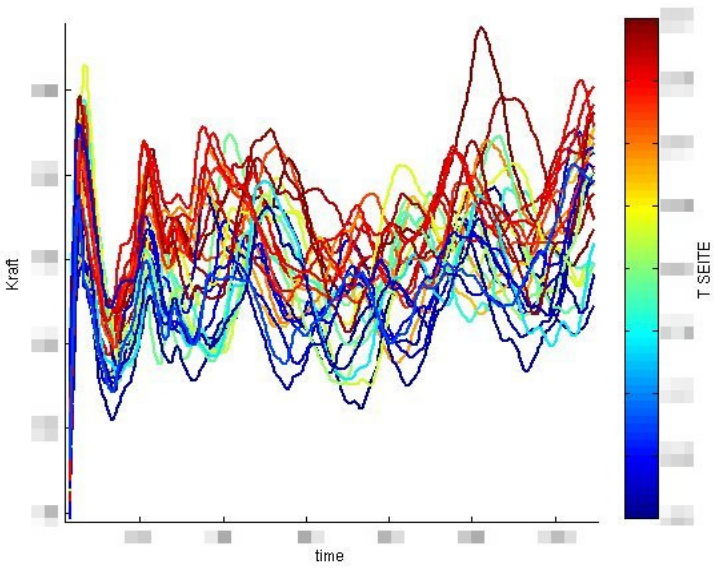
- Improvement of the energy absorption of a crash box for a reduced maximum force level



Application of Shape Optimization with LS-OPT

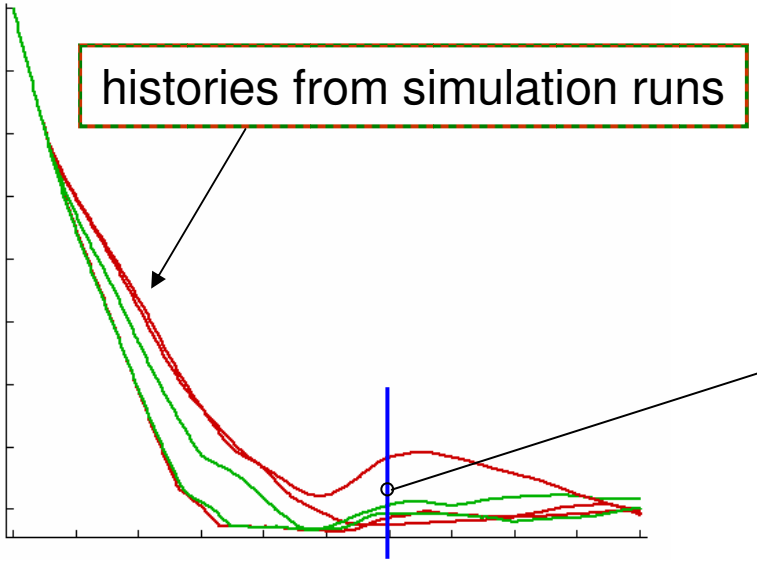
- History curves
- Color of the curves to display the respective value of a variable, response or composite

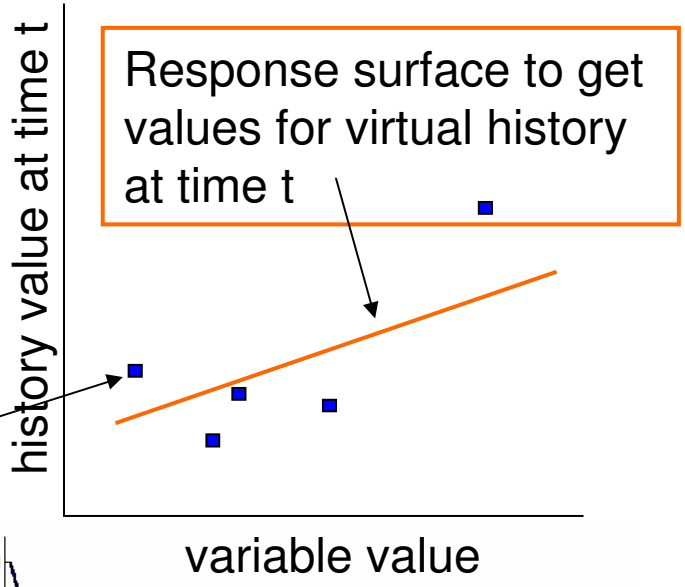




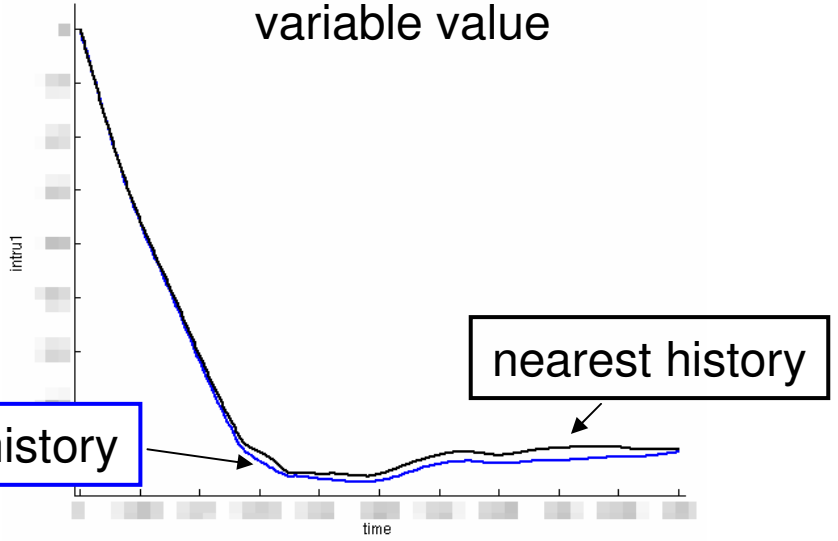
DOE Sensitivity Analysis with LS-OPT

§ Calculation of virtual histories





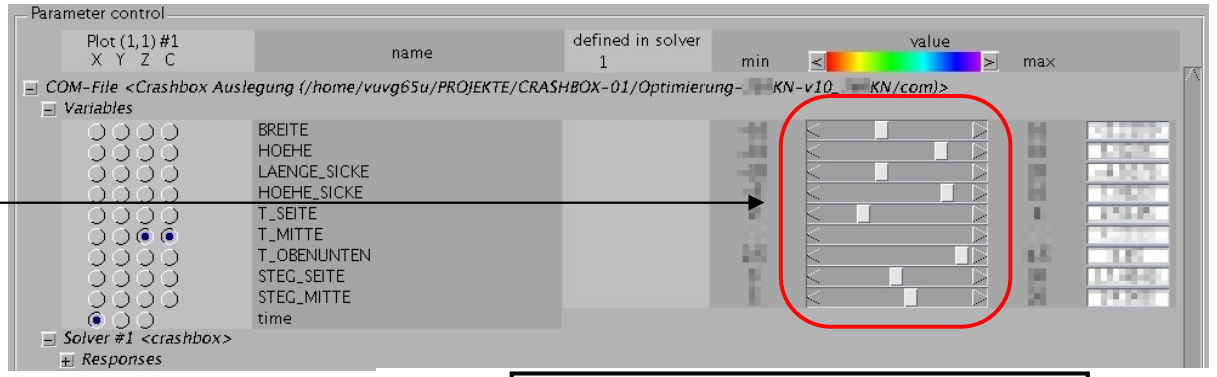
calculation for equidistant time values
↳ virtual history

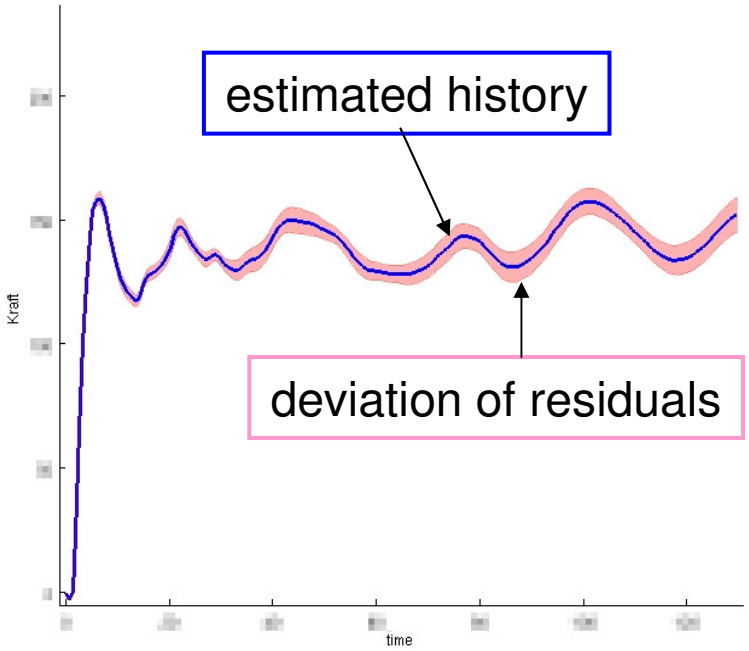


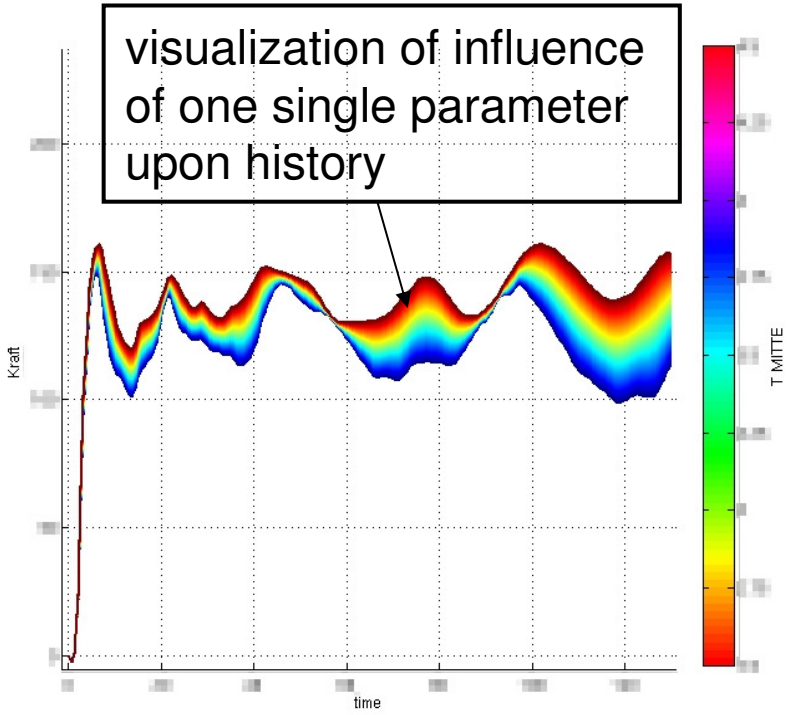
Application of Shape Optimization with LS-OPT

§ Virtual Histories

slider to select parameter constellation

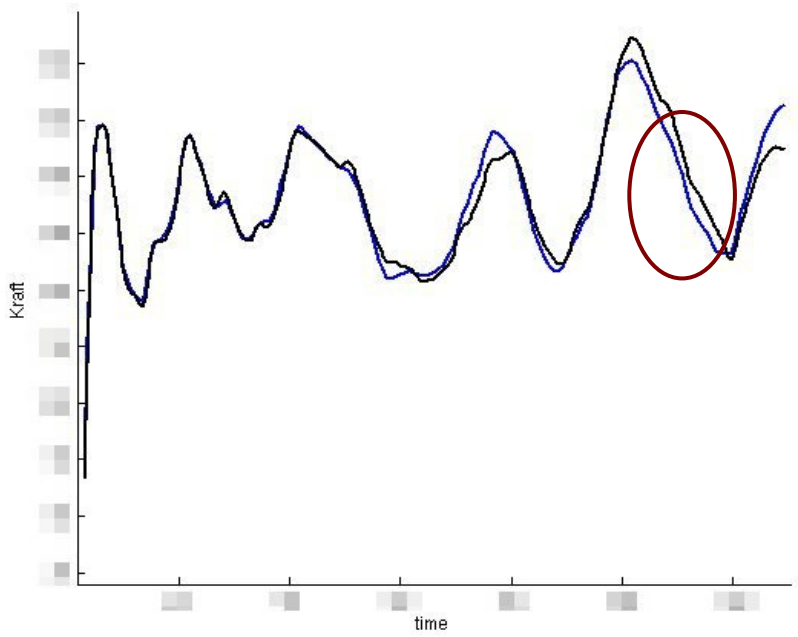




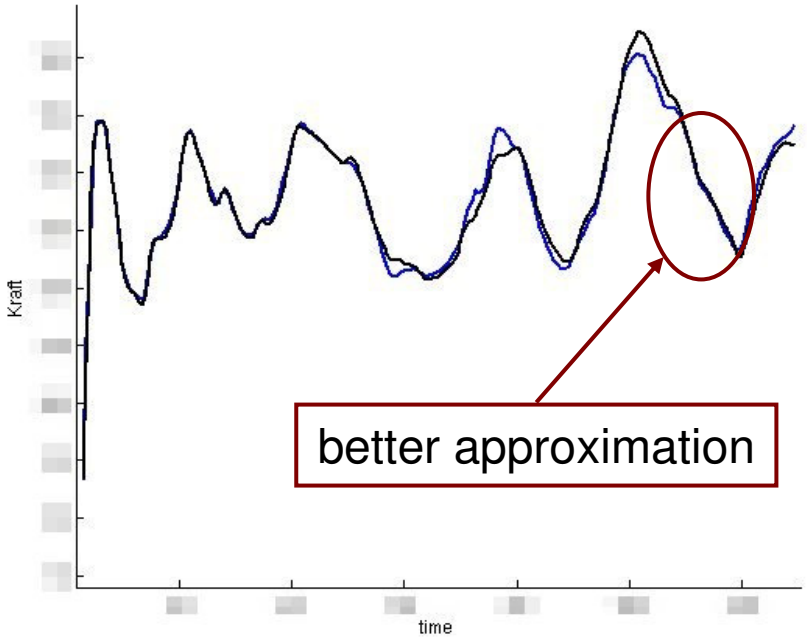


Application of Shape Optimization with LS-OPT

§ Comparison of different meta-model types

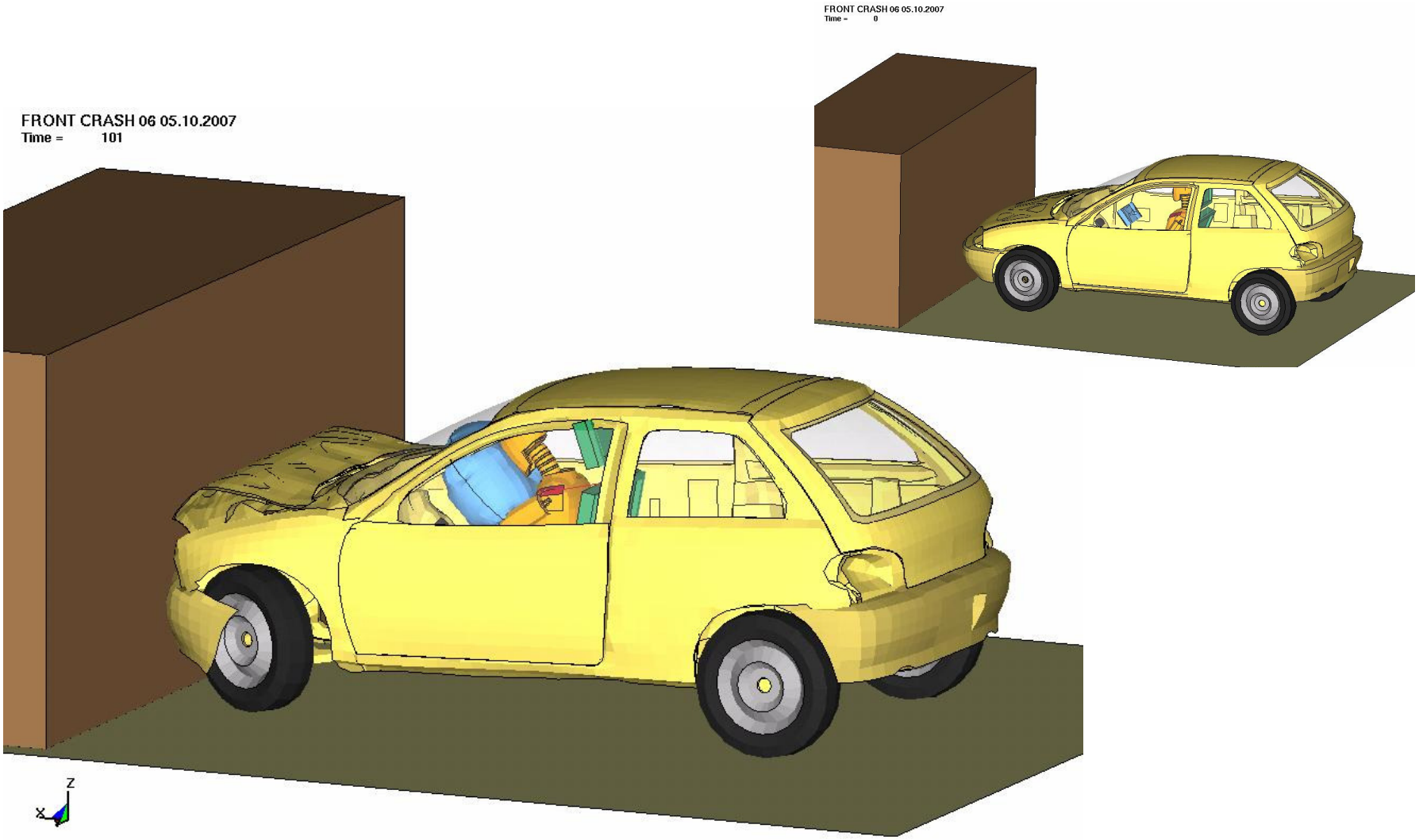


Linear approximation



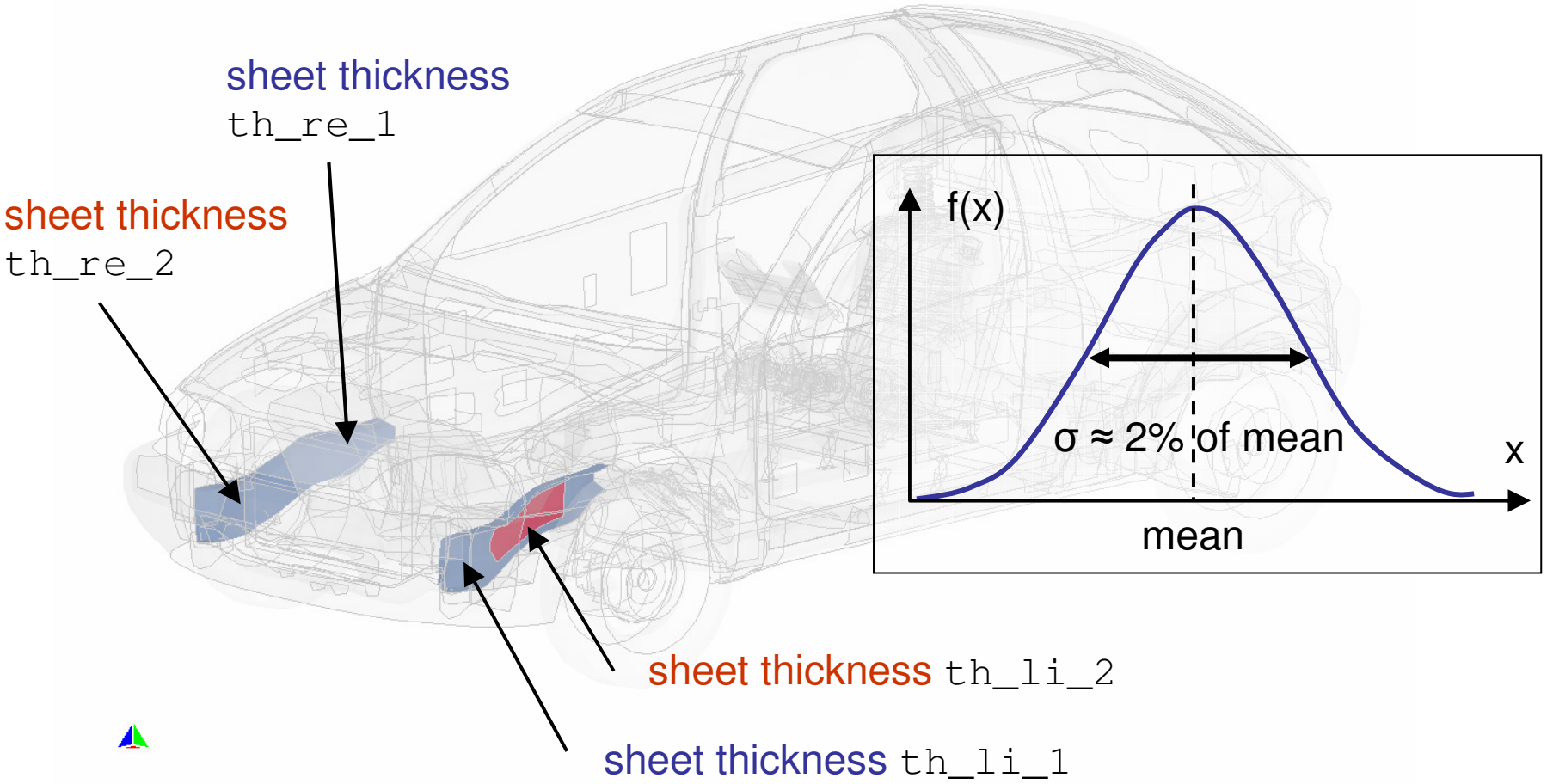
Moving least squares approximation

Stochastic Analysis – Front-Crash

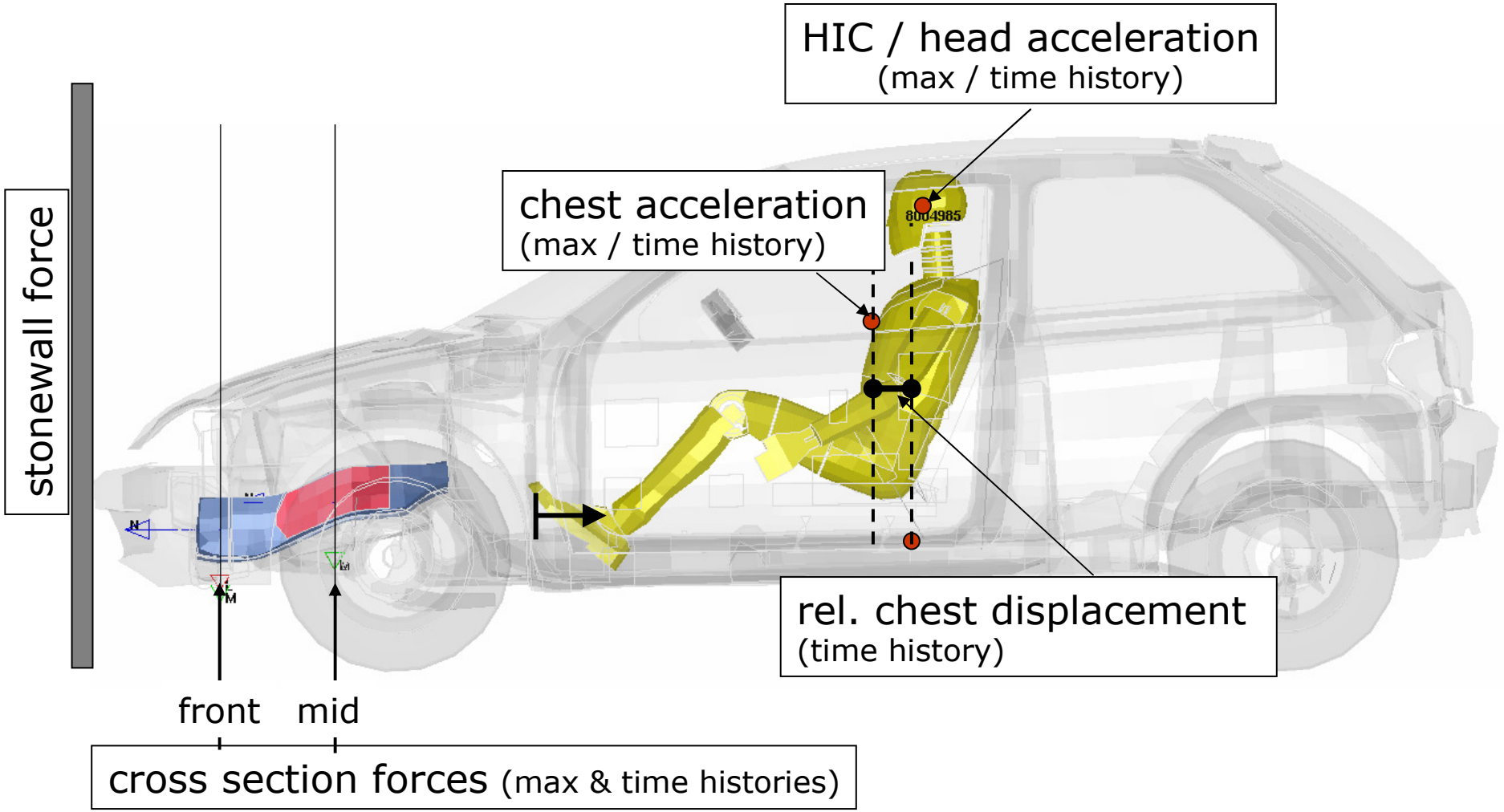


Stochastic Analysis – Front-Crash

Stochastic parameters



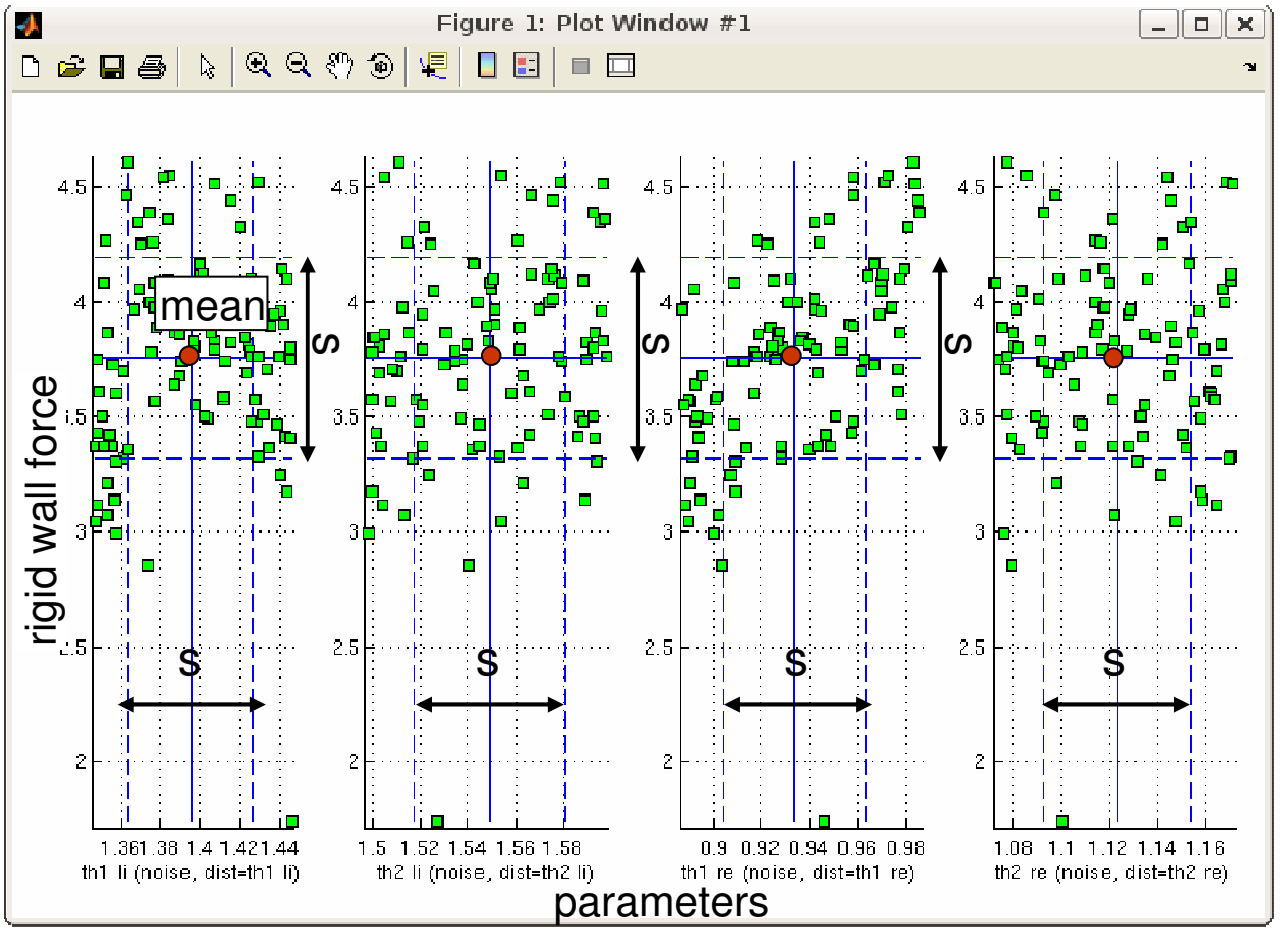
Stochastic Analysis – Front-Crash



Stochastic Analysis – Front-Crash

Statistics / Plots

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

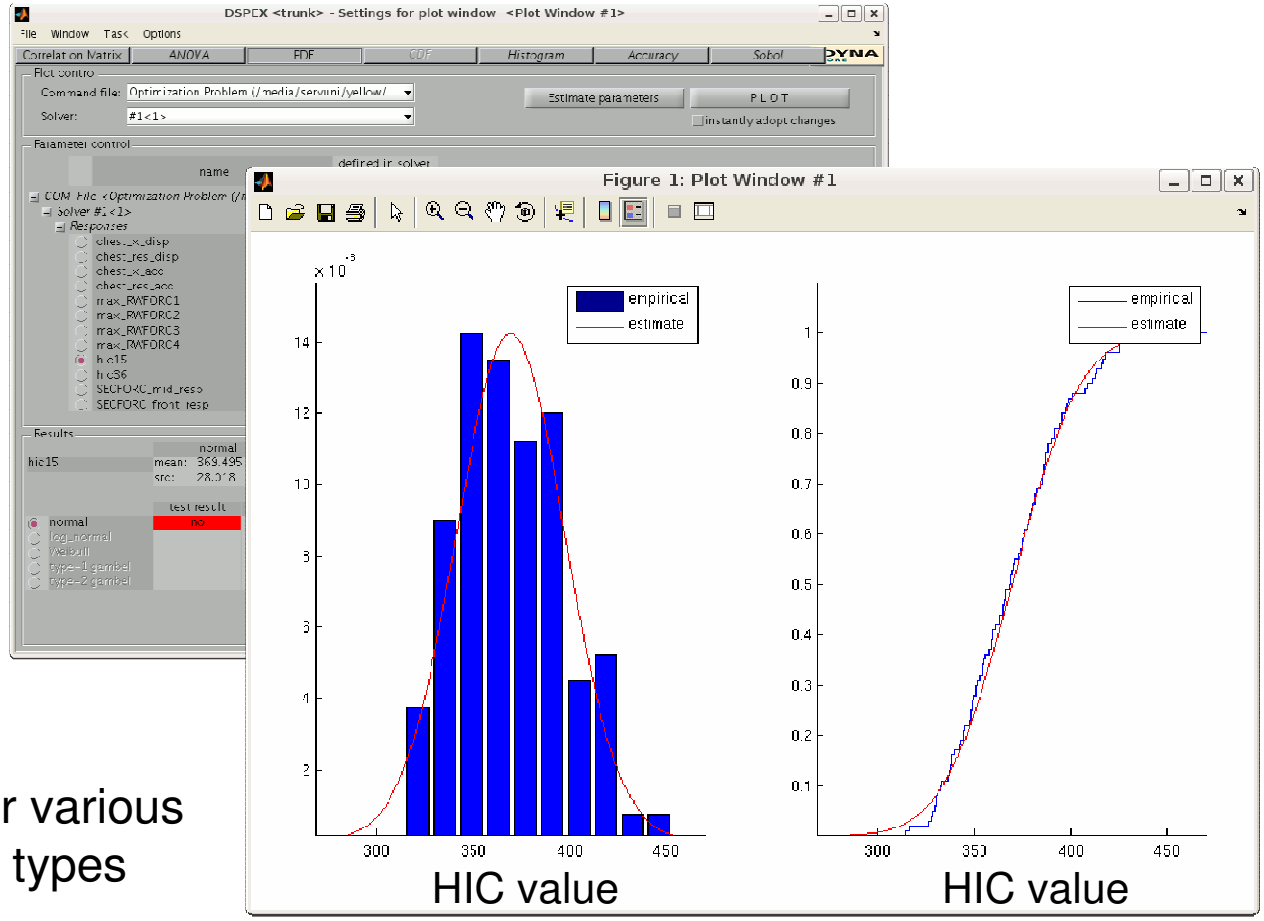


Stochastic Analysis – Front-Crash

Probability distribution type / empirical distribution

Visualization of …

- PDF
- CDF
  (both empirical
  and estimated)
- histogram

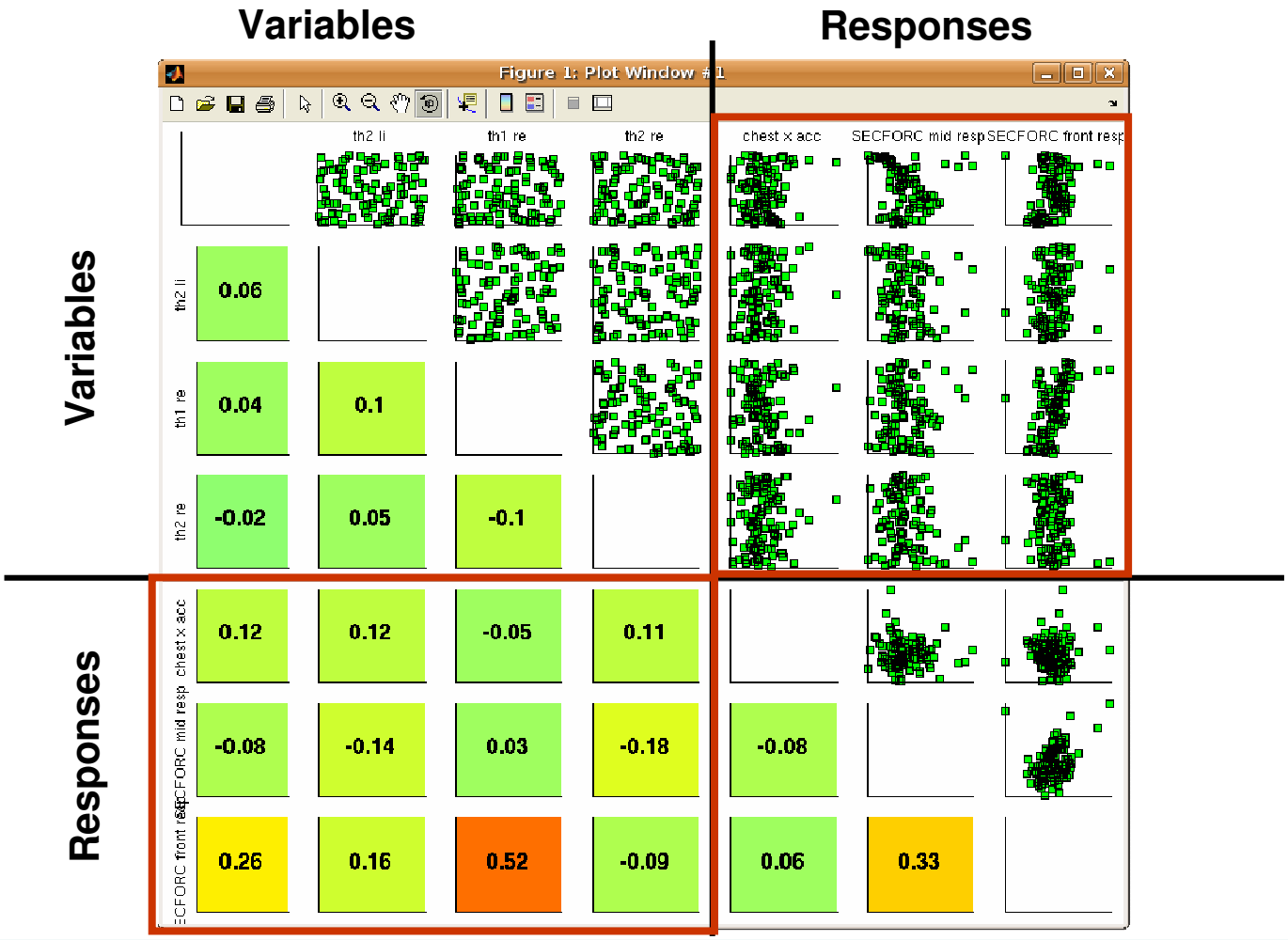


Statistical test (K-S)

- goodness of fit test for various probability distribution types

Stochastic Analysis – Front-Crash

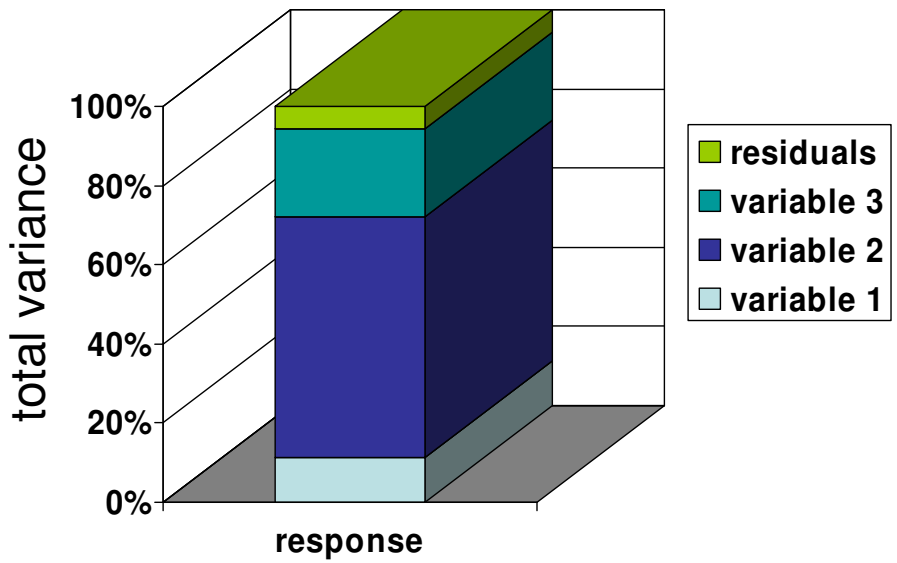
Statistics / linear Sensitivity: Correlation matrix



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



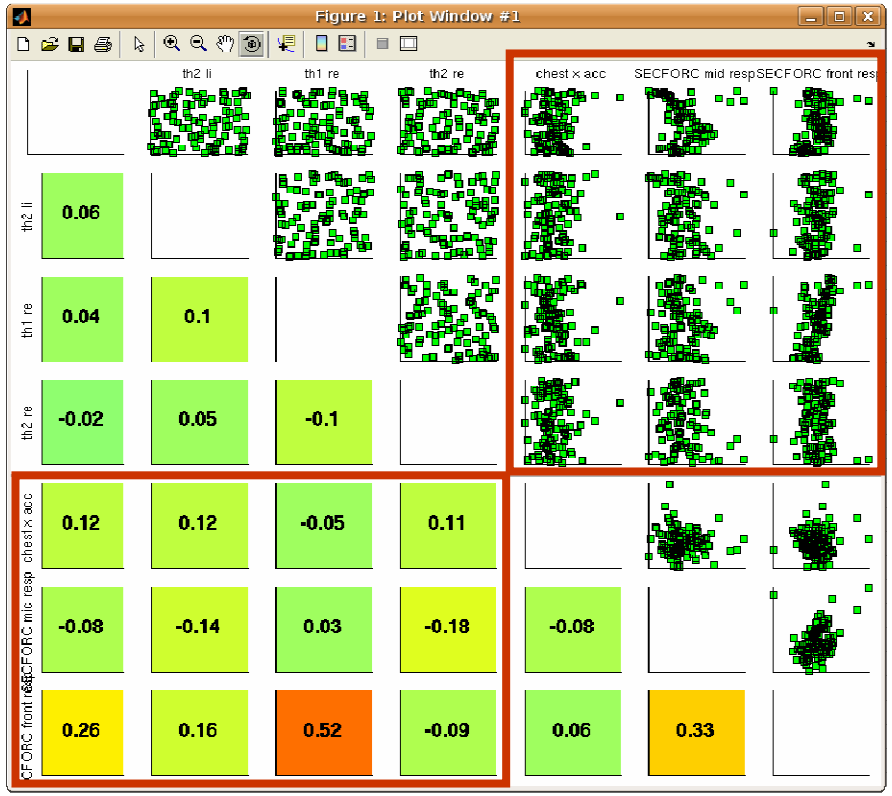
Sobol' indice of variable v_i

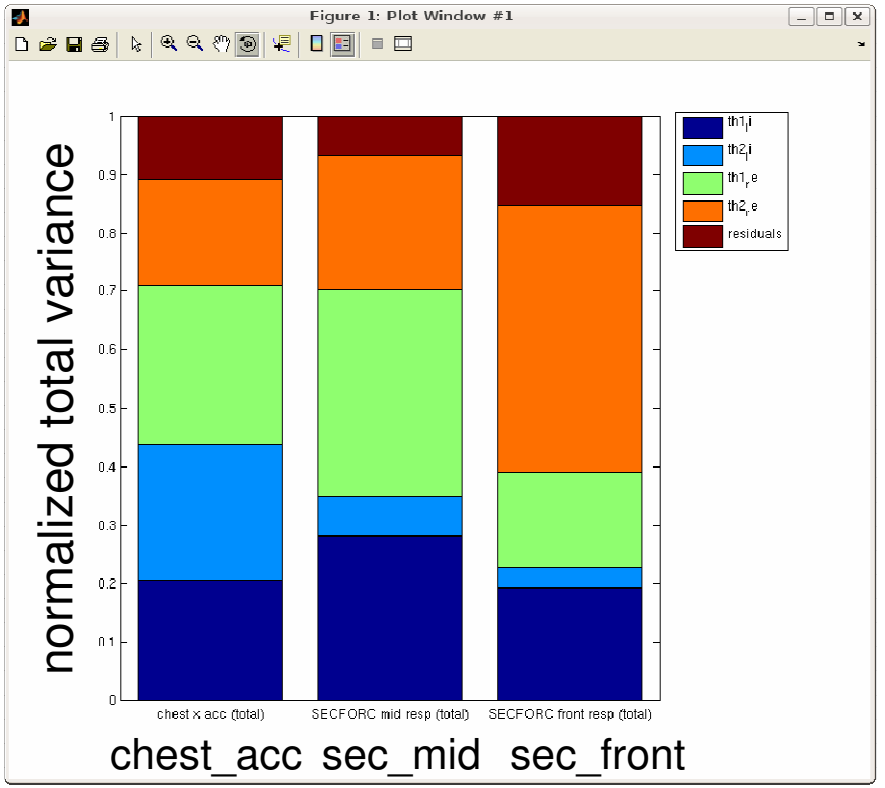
$$S_i = \frac{\text{variance caused due to } v_i}{\text{total variance of response}}$$

determination computational expensive ▸ meta models are applied

Stochastic Analysis – Front-Crash

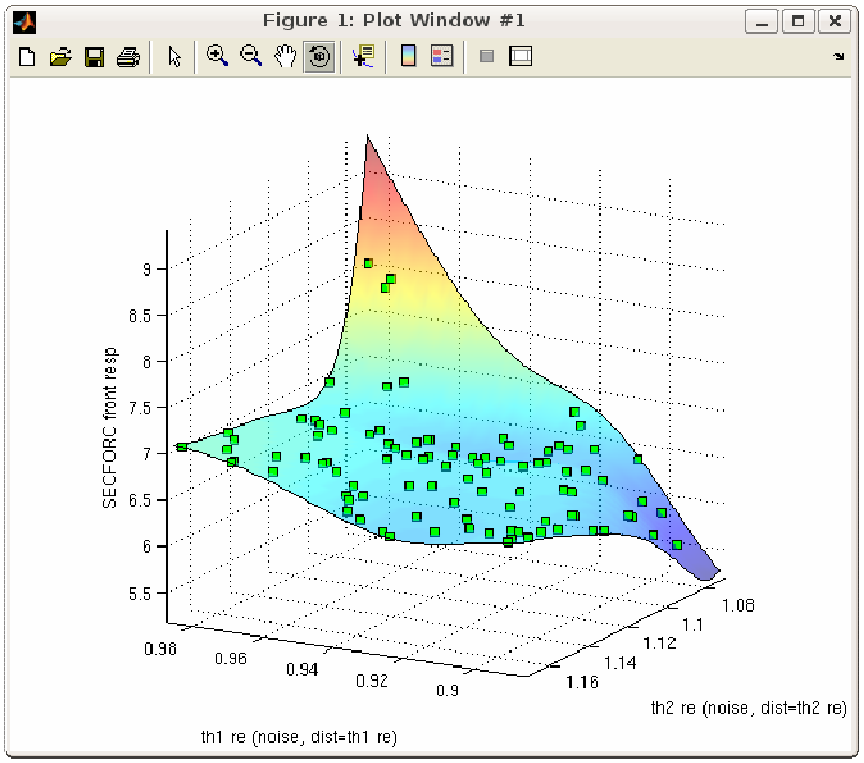
linear vs. non-linear Sensitivity: Sobol' indices / Correlation

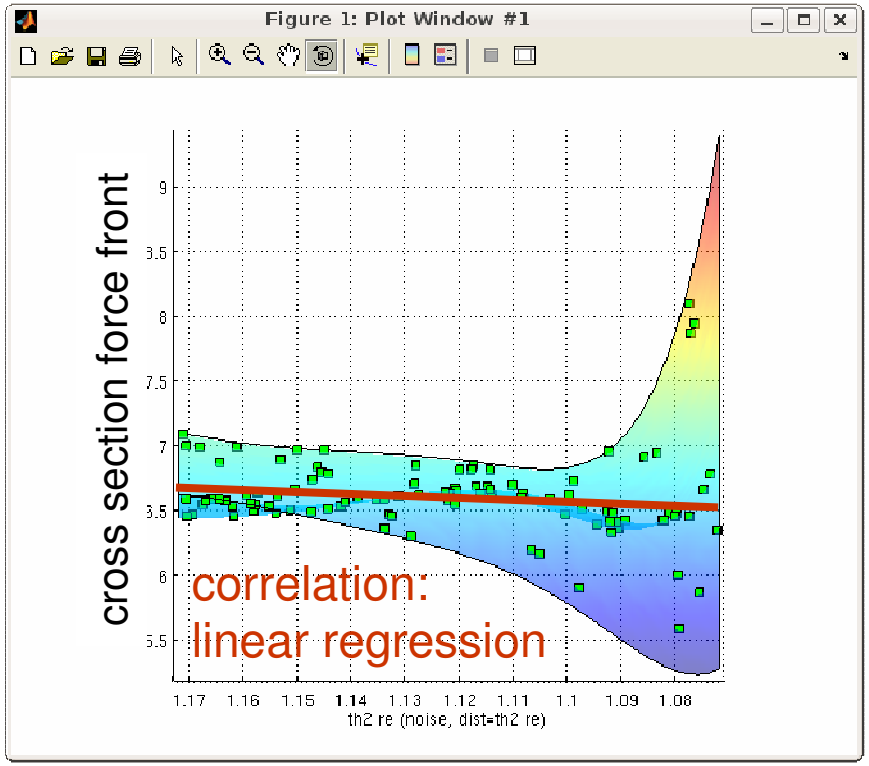




Stochastic Analysis – Front-Crash

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