SKF

Parametric Studies in Product Development using SKF BEAST on Multi-Processor Platforms

MODPROD 2010, Linköping, Sweden

Dag Fritzson,
SKF ERC

2010-02-10

Outline of presentations

BEAST?

SKF Product Development Process and Simulation

Example of using Design For Six Sigma (DFSS) tools (quality, parameter studies, and statistics)

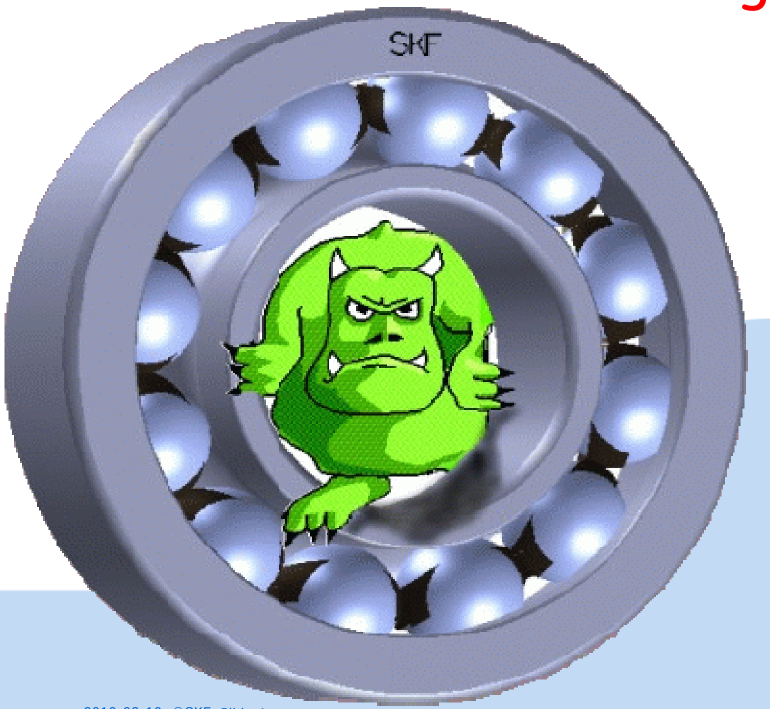
Parallel Computation

Summary

BEAST

BEAring Simulation Tool

-The devil is in the details



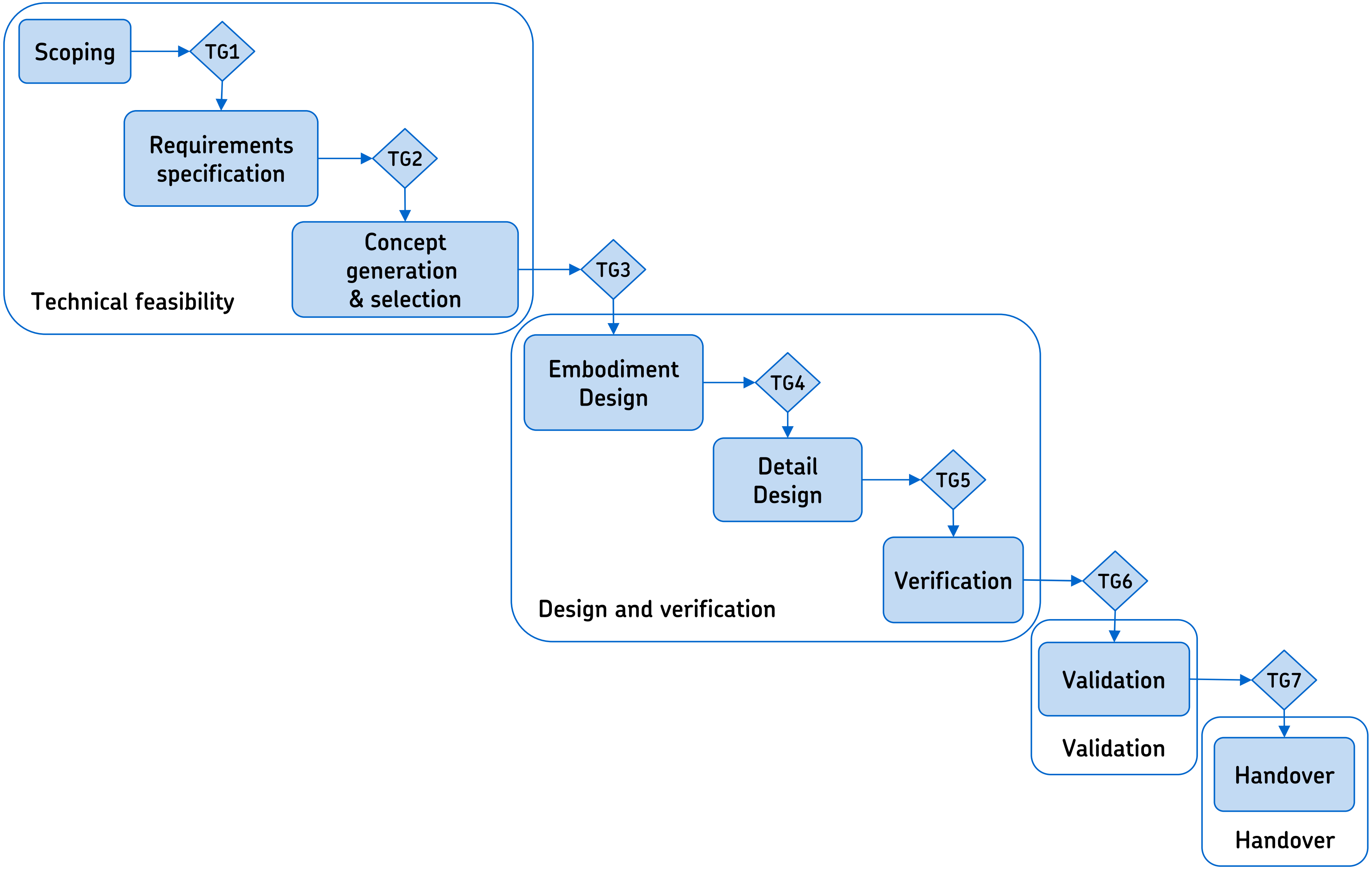
BEAST - a virtual test rig

- Multi-body simulation software
- Specialized in contact problems
- Detailed surface description
- Accurate tribology
- Application operating conditions
- Focus on creating understanding of systems with contacts
- BEAST was originally developed for rolling bearings, but can be used for any “contacting” machine element

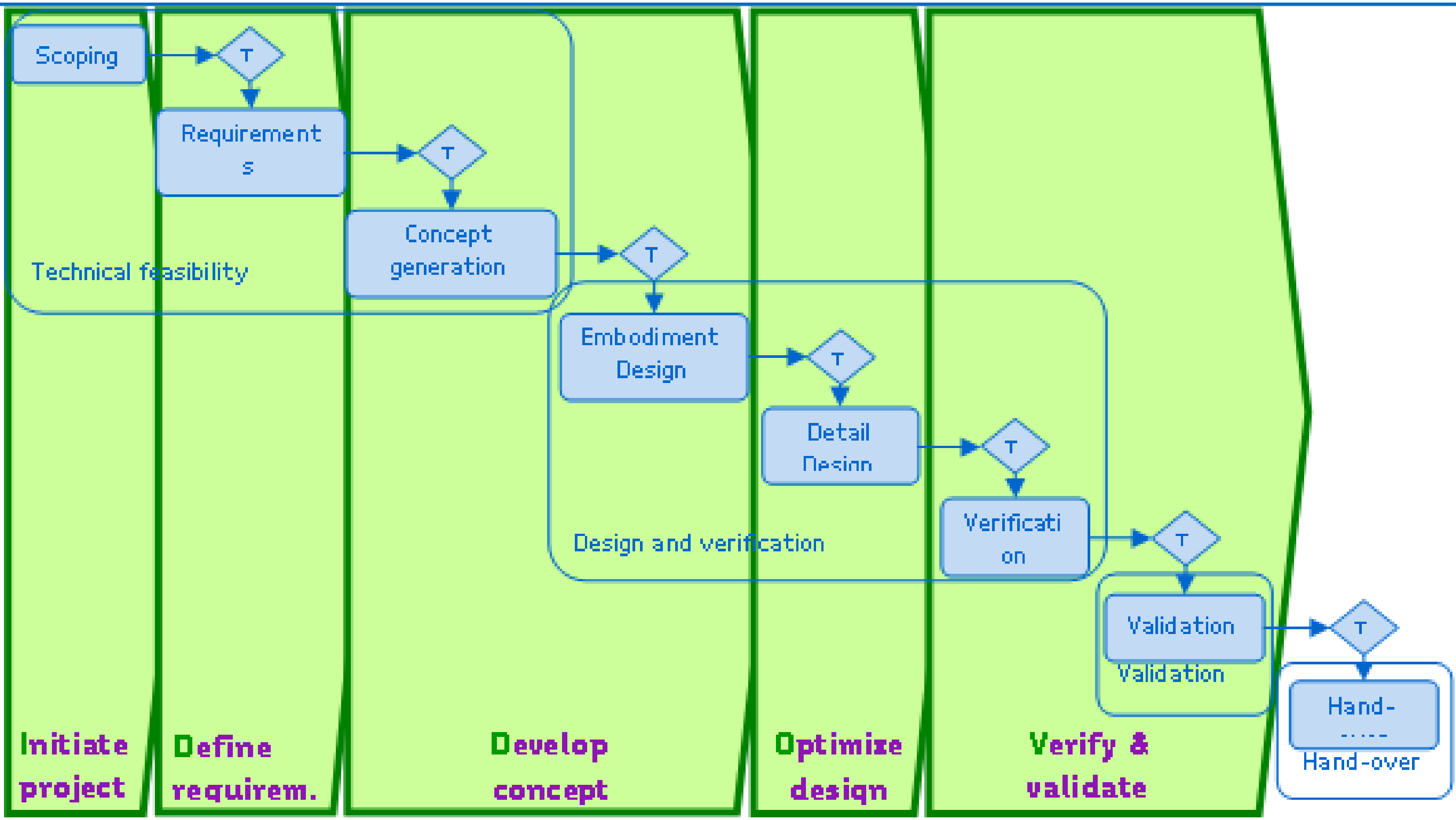
1

The Product Development Process and Simulation

Product Development Process (PDP)



PDP and Design for Six Sigma (DfSS) integrated



The EASY work process

Requirements

Translation

Load case date bases
10-100 dynamic load cases

Automatic simulation of selected load cases with one command

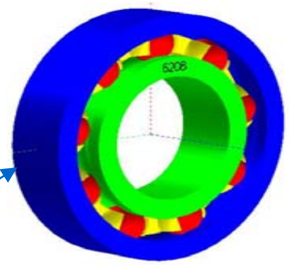
Automatic data reduction from 4D/3D to scalar values

Performance criteria
BSL criteria

Comprehensive presentation

Tables or diagrams, load case versus criteria

Reduced or full model



Design parameters
(e.g., geometry, tolerances, surface properties, material, etc)

Sensitivity/robustness analysis

Improve/optimize product

Multi-criteria optimization
(DoE or “automatic”)

Automatic translation

Manufacturing process parameters

The EASY work process – Concept studies

Requirements

Translation

Load case date bases
A few selected load cases

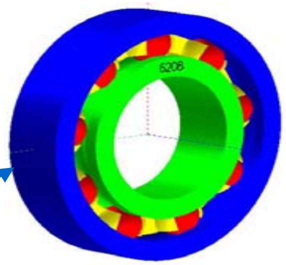
Automatic simulation of selected load cases with one command

Automatic data reduction from 4D/3D to scalar values

Performance criteria
BSL criteria

Comprehensive presentation

Reduced or full model



Tables or diagrams, load case versus criteria

A few main design parameters
(e.g., geometry, tolerances, surface properties, material, etc)

Sensitivity/robustness analysis

Improve/optimize product

Automatic translation

Multi-criteria optimization
(DoE or “automatic”)

Manufacturing process parameters

The EASY work process – Detailed design

Requirements

Translation

Load case date bases
Selected load cases

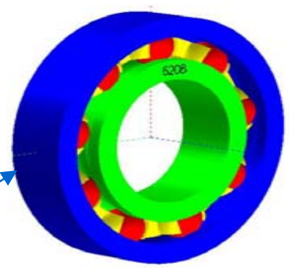
Automatic simulation of selected load cases with one command

Automatic data reduction from 4D/3D to scalar values

Performance criteria
BSL criteria

Comprehensive presentation

Reduced or full model



Tables or diagrams, load case versus criteria

All relevant design parameters
(e.g., geometry, tolerances, surface properties, material, etc)

Sensitivity/robustness analysis

Improve/optimize product

Automatic translation

Multi-criteria optimization
(DoE or “automatic”)

Manufacturing process parameters

The EASY work process - Verification

Requirements

Translation

Load case date bases
Load cases that cover requirement space

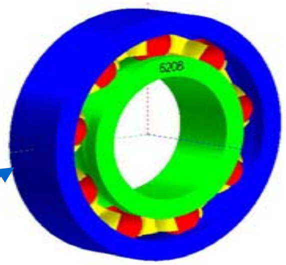
Automatic simulation of selected load cases with one command

Automatic data reduction from 4D/3D to scalar values

Performance criteria
BSL criteria

Comprehensive presentation

Reduced or **full** model



Tables or diagrams, load case versus criteria

Fixed design parameters (Possible study of tolerances).

Automatic translation

Fixed manufacturing process parameters

Examples of tools that can be used

Minitab statistical software (www.mintab.com)

- is a standard SKF DfSS and Six Sigma tool
- it covers statistics, DoE, optimization, etc.

DoEBeast/Beauty

- it is small but focused on DfSS usage, i.e., parametric studies (DoE), sensitivity/robustness analysis
- it has import/export to minitab
- it has optimal connection/usage of BEAST

modeFRONTIER (www.esteco.com)

- is a general tool focused on optimization

HyperStudy (www.altairhyperworks.com)

- is a general tool

Conclusion

The DFSS supports use of simulation.

There is an expressed intention in SKF to use modelling and simulation early in the PDP, and to larger extent.

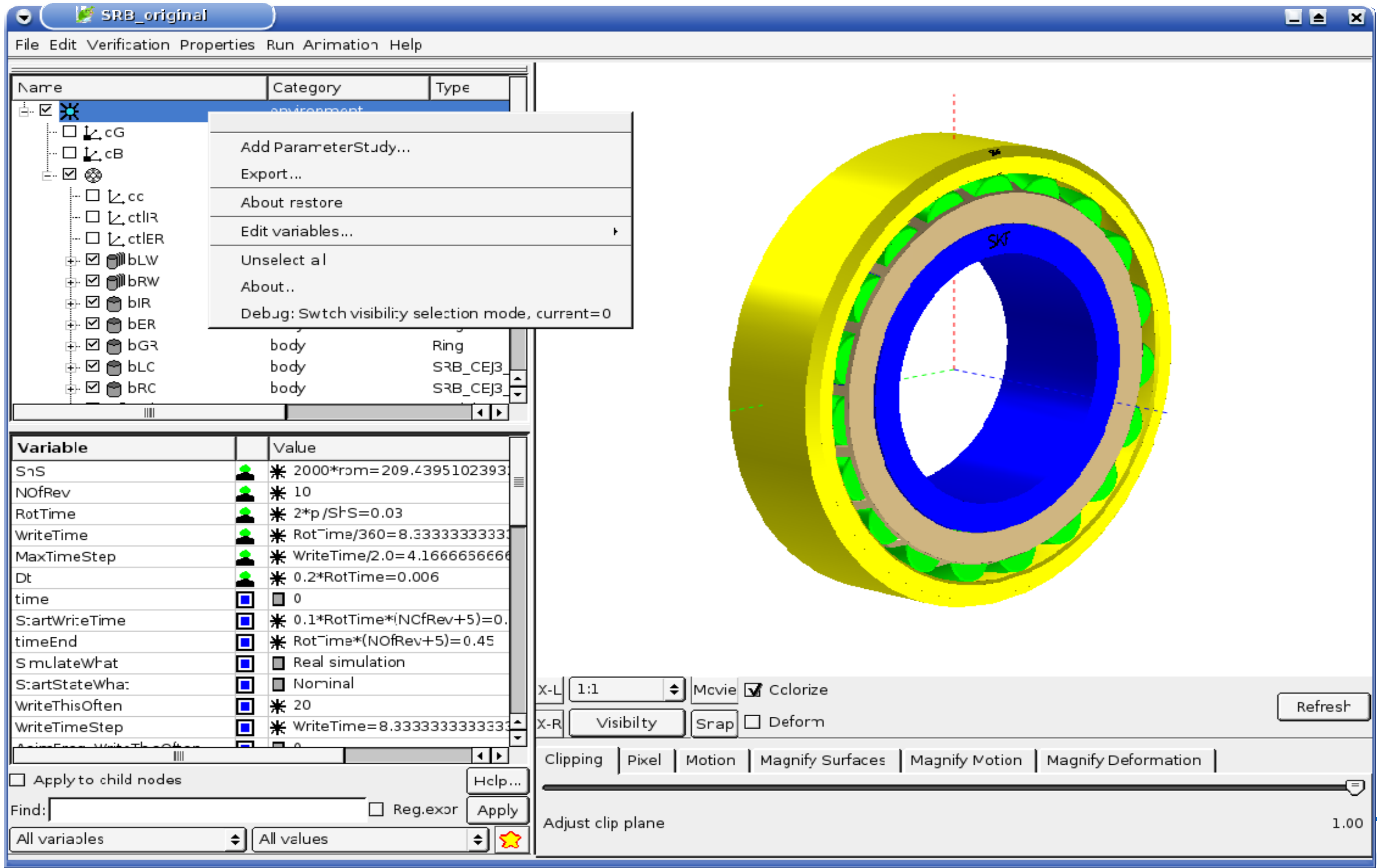
•

2

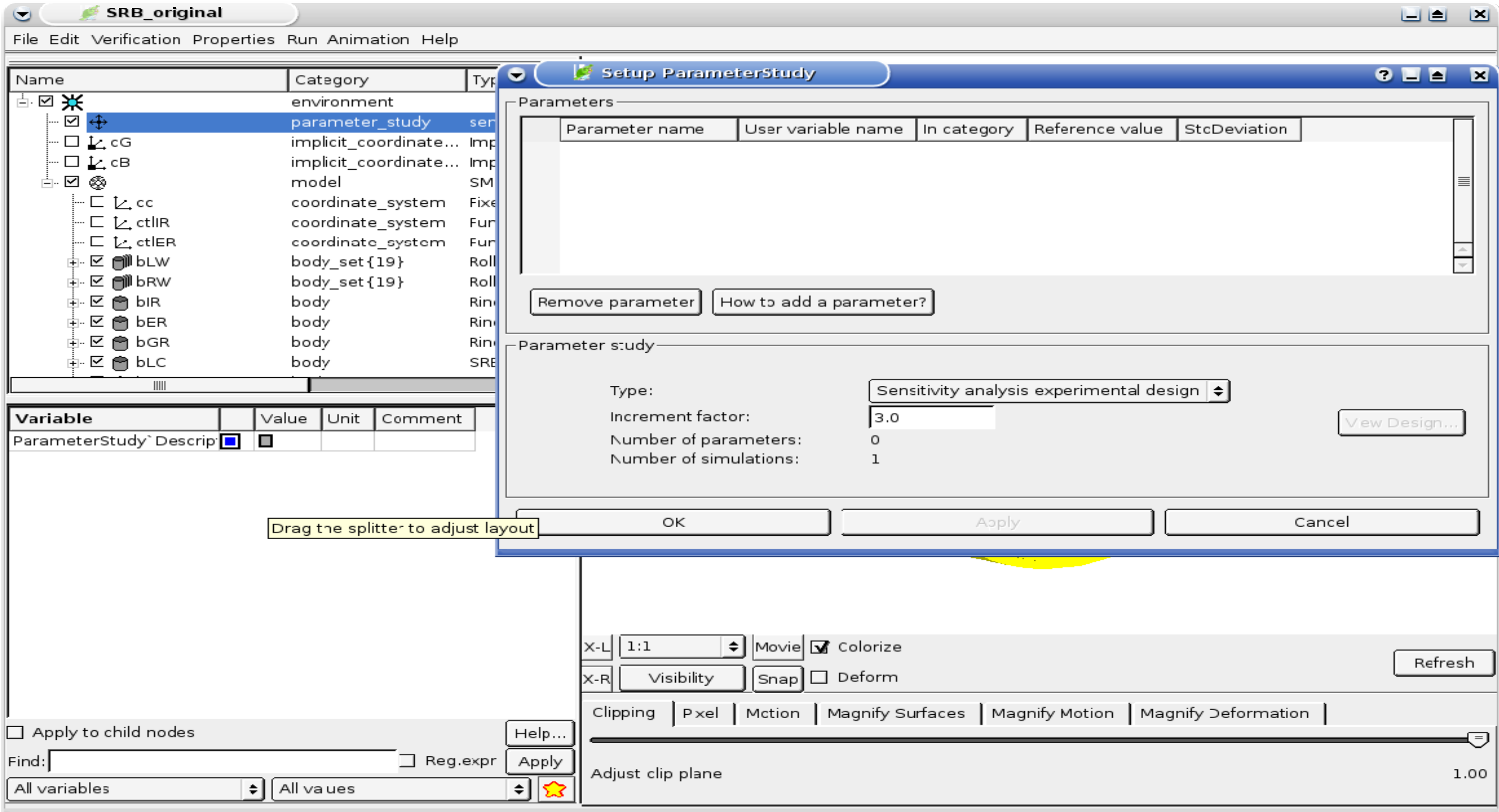
Examples of a Parametric Study using DFSS tool

Setting up a screening design

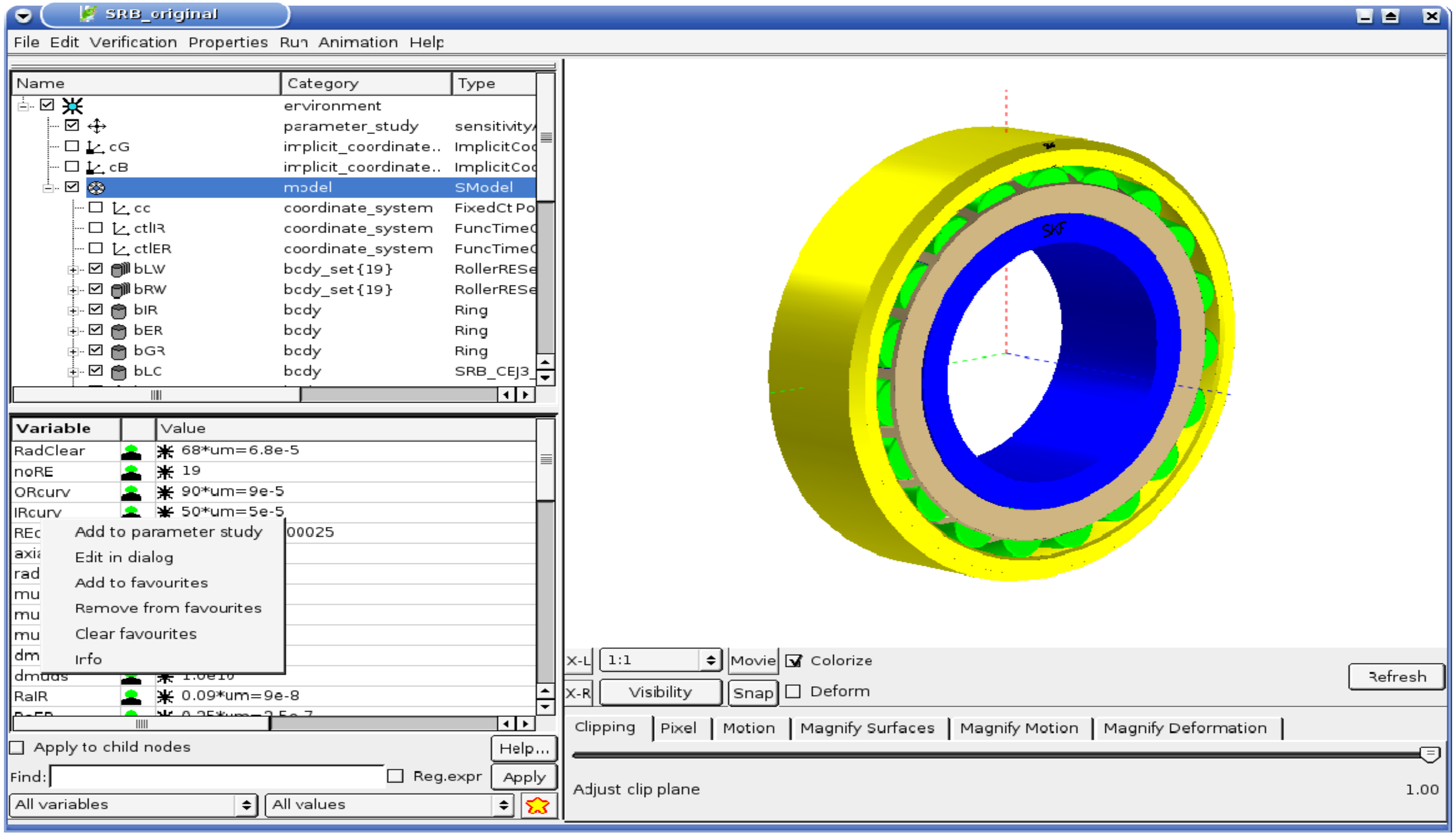
A BEAST model is turned into a parameter study by adding a *parameter_study* node (right click environment):



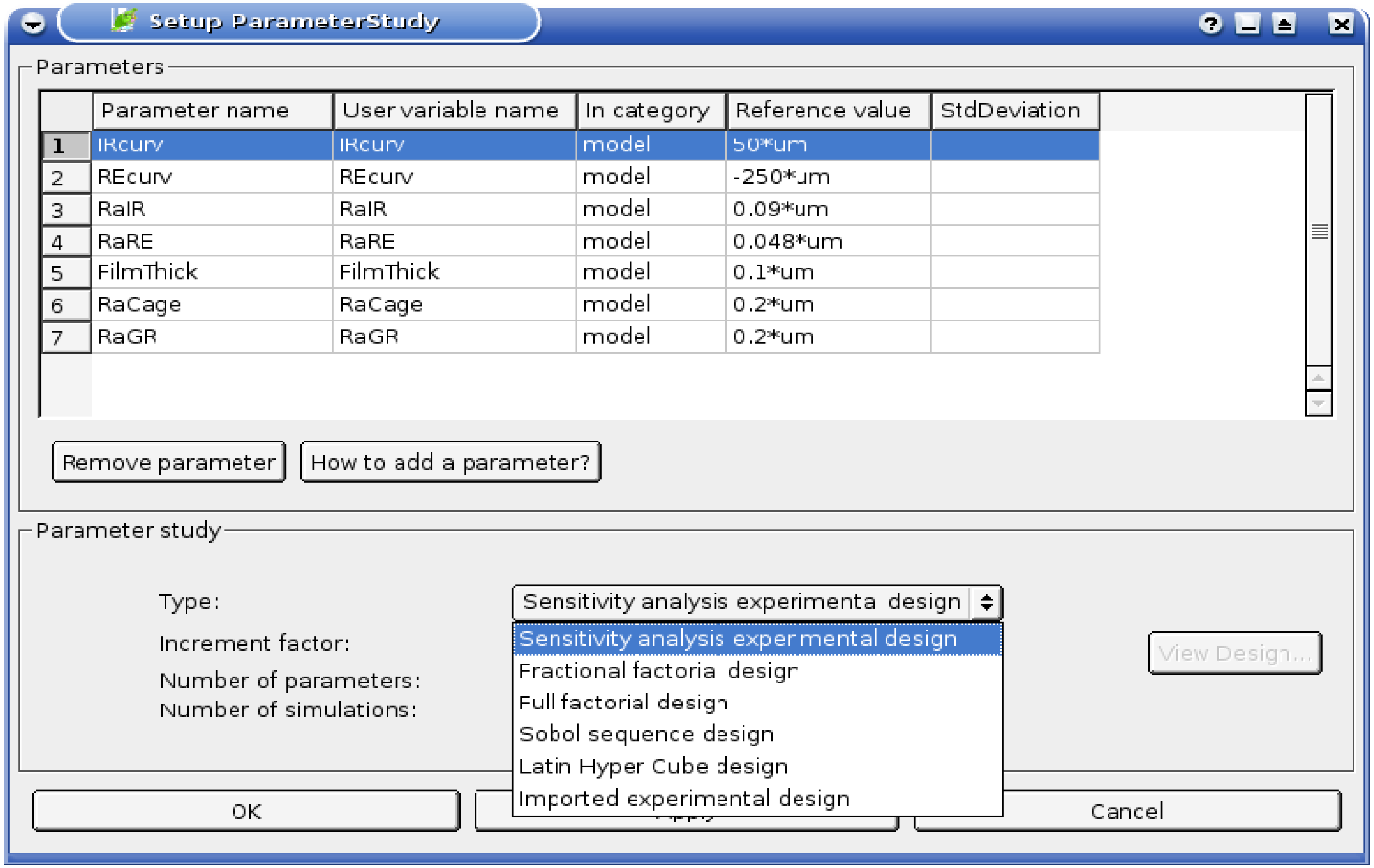
Screening...(cont.)



Screening...(cont.)

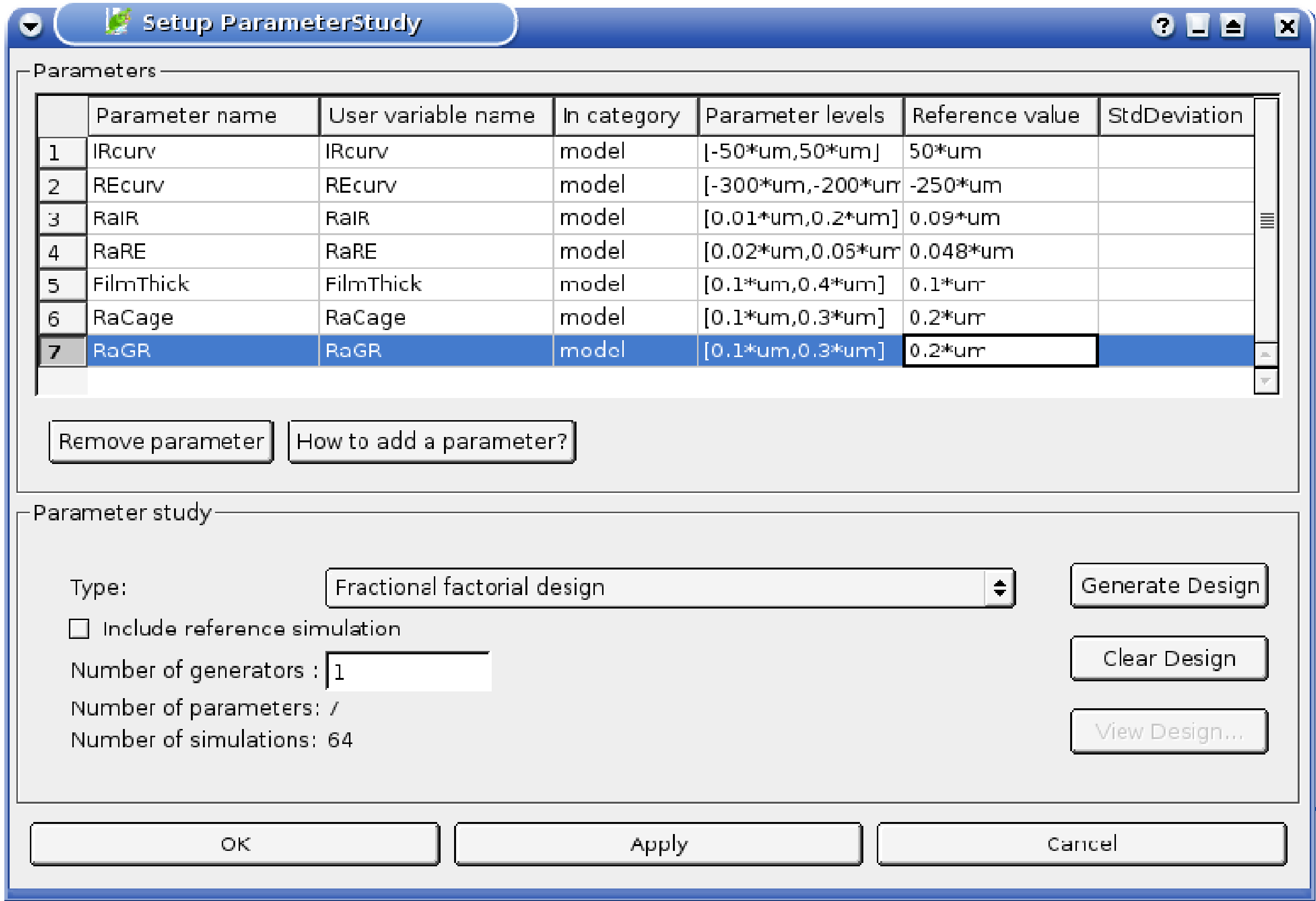


Screening...(cont.)

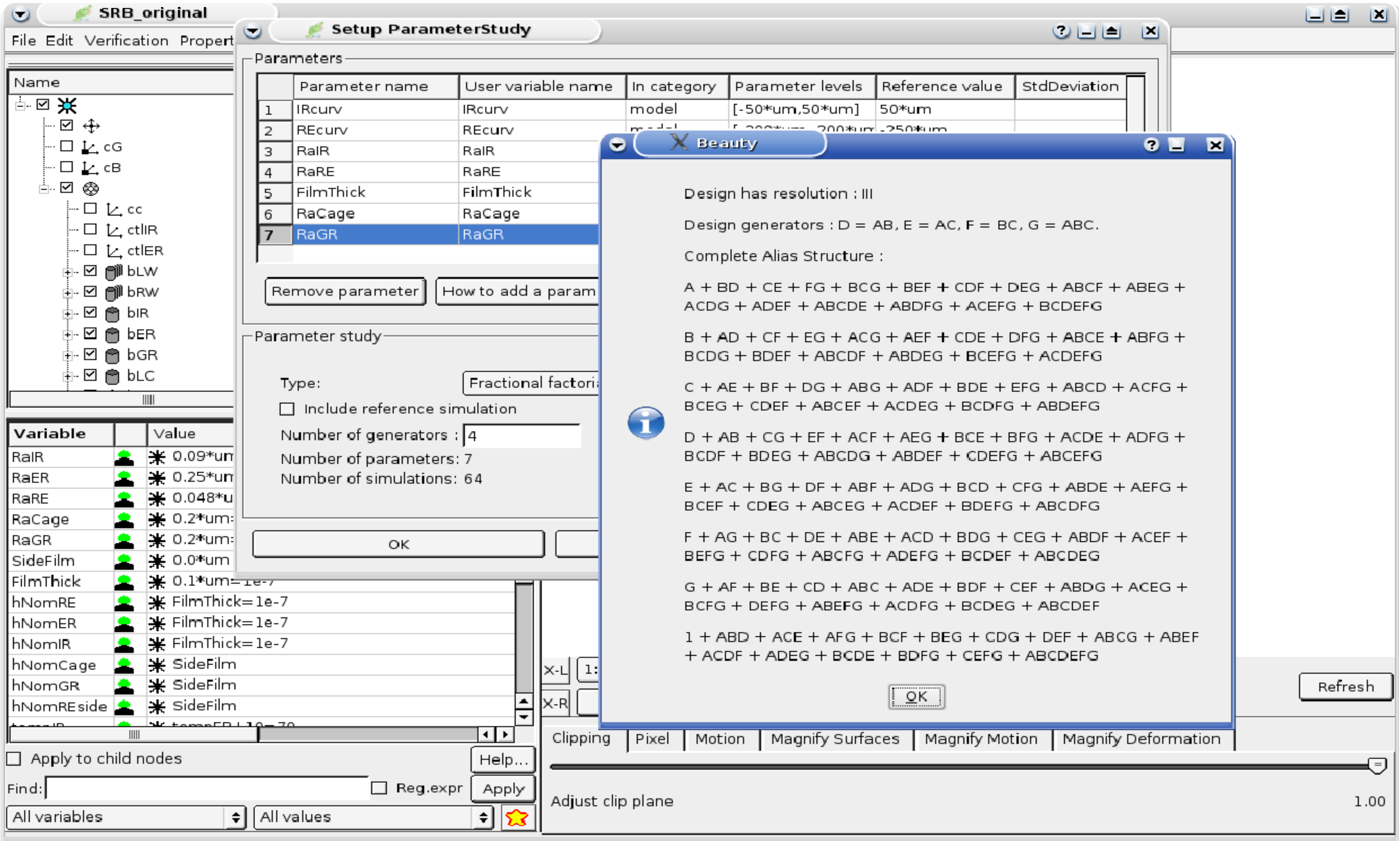


Screening...(cont.)

Choose fractional factorial and enter the lower and upper limits of your parameters #simulations = $2^{(\text{parameters} - \#\text{generators})}$:

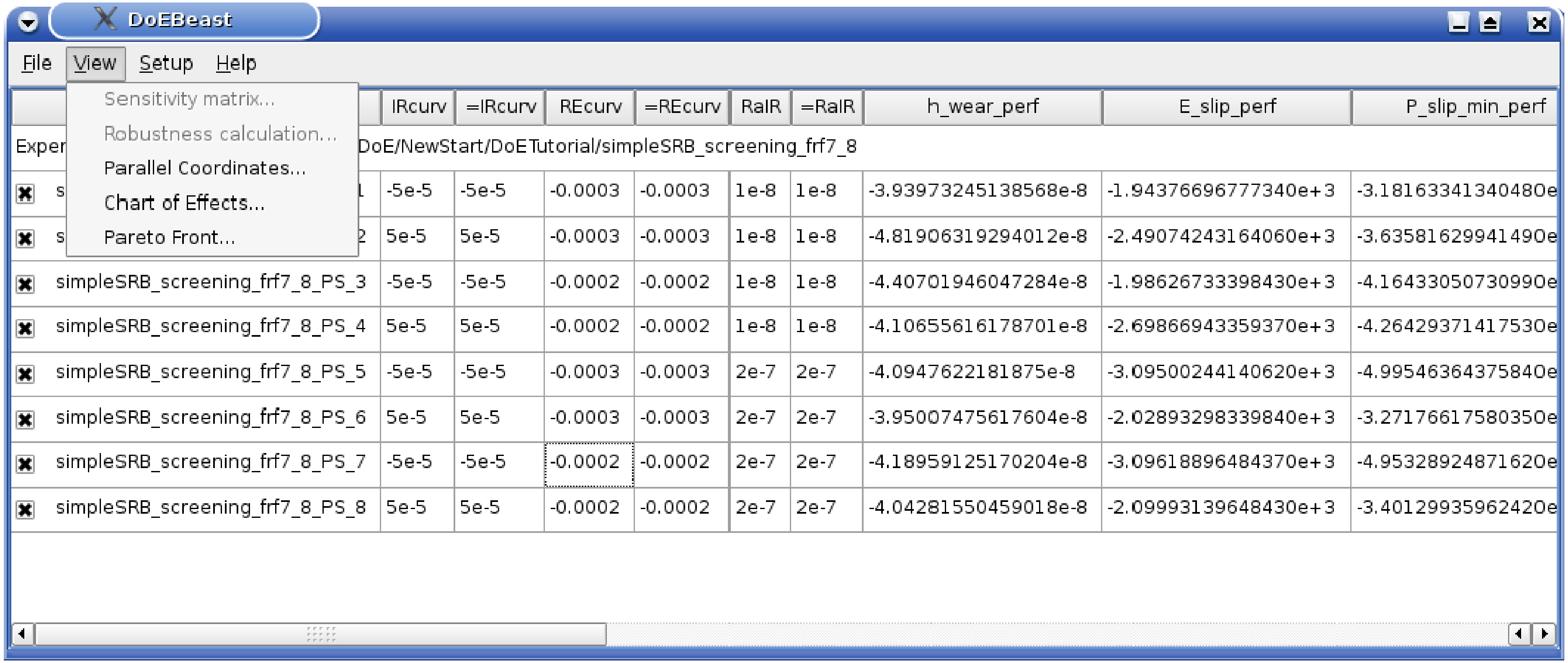


Screening...(cont.)



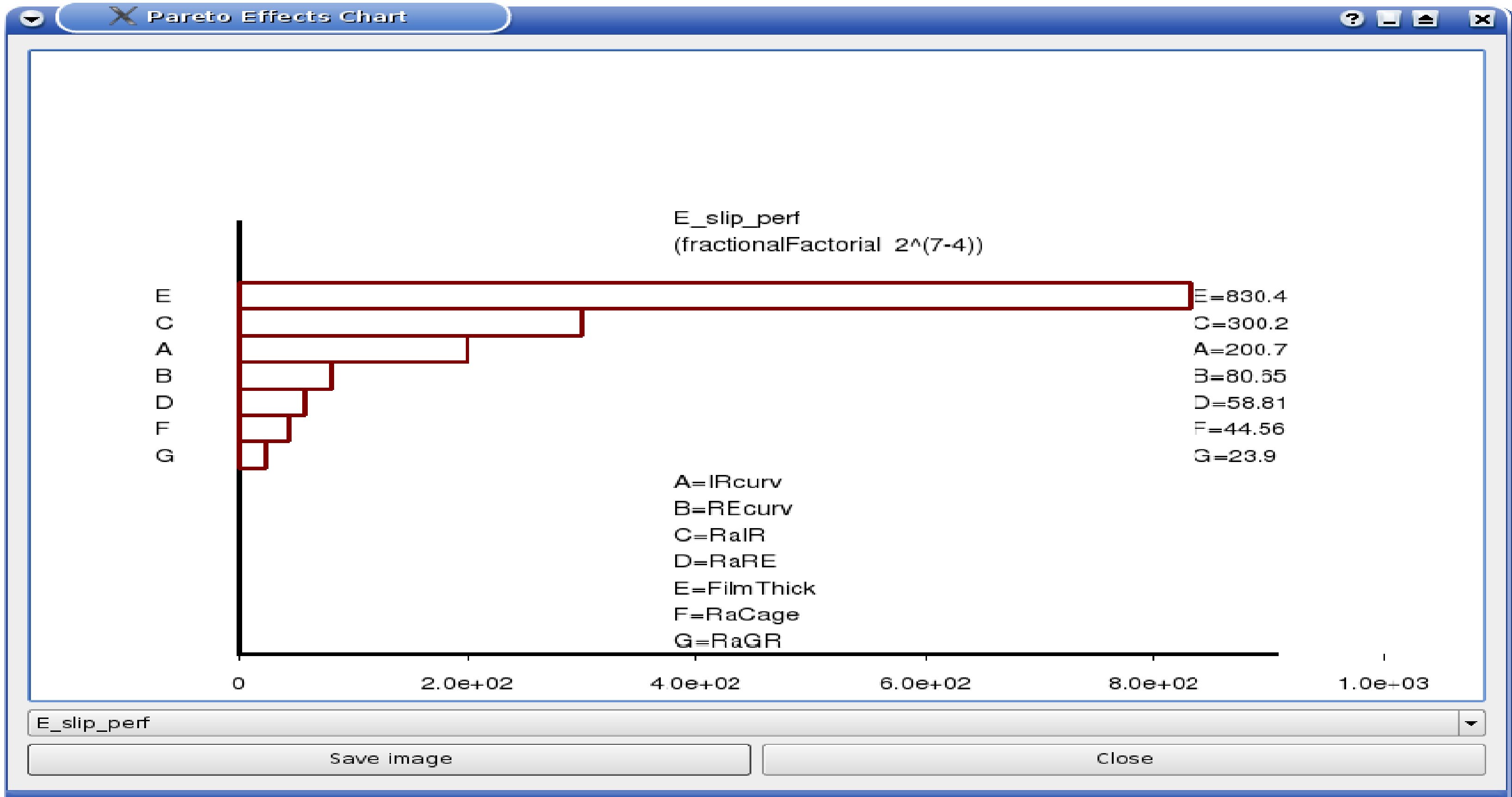
Screening…(cont.)

Choose *Chart of Effects* from menu. We decide to look at *E_slip_perf*:



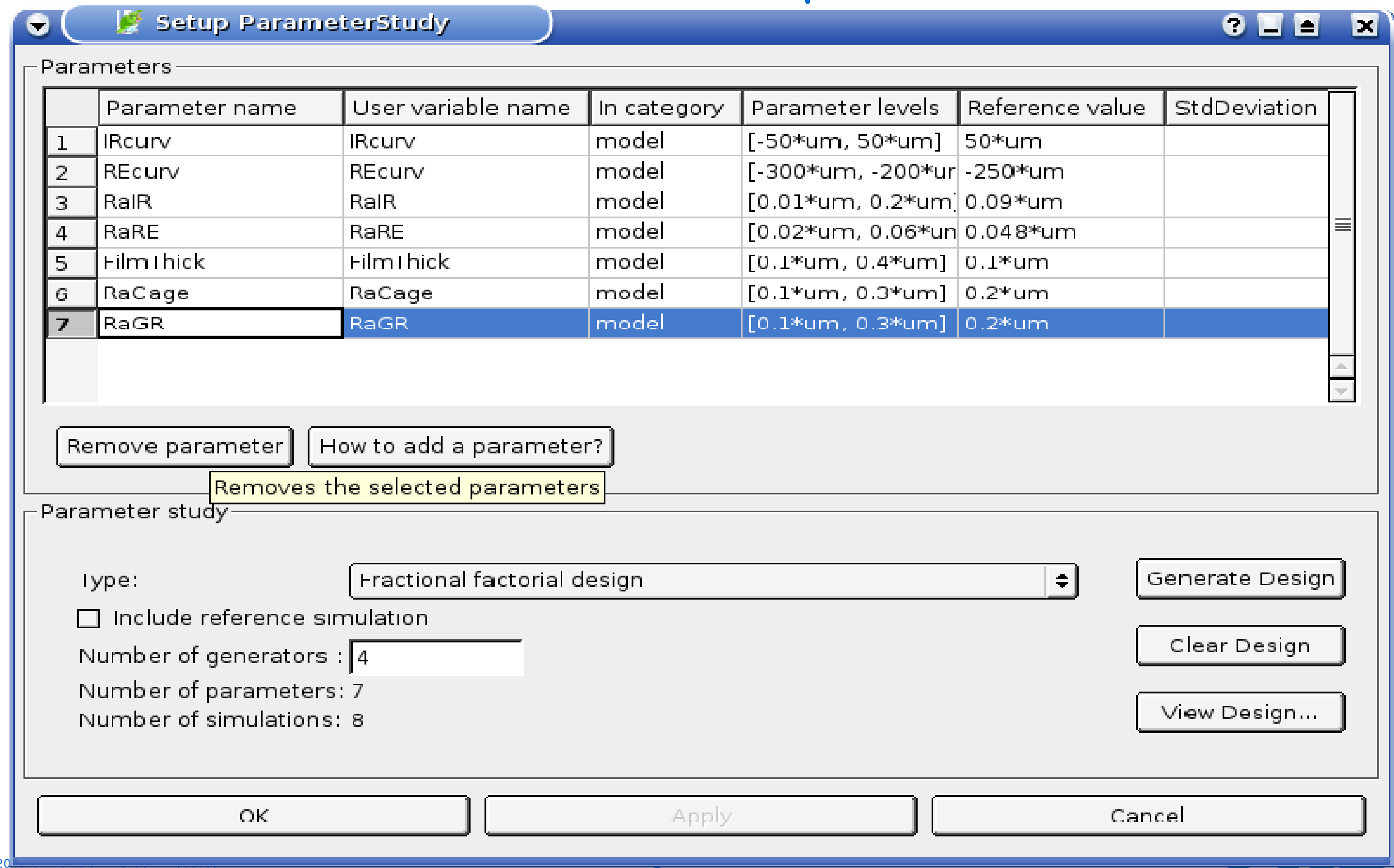
Screening...(cont.)

Graph displaying Pareto effects (N.B. Only first order effects are shown):



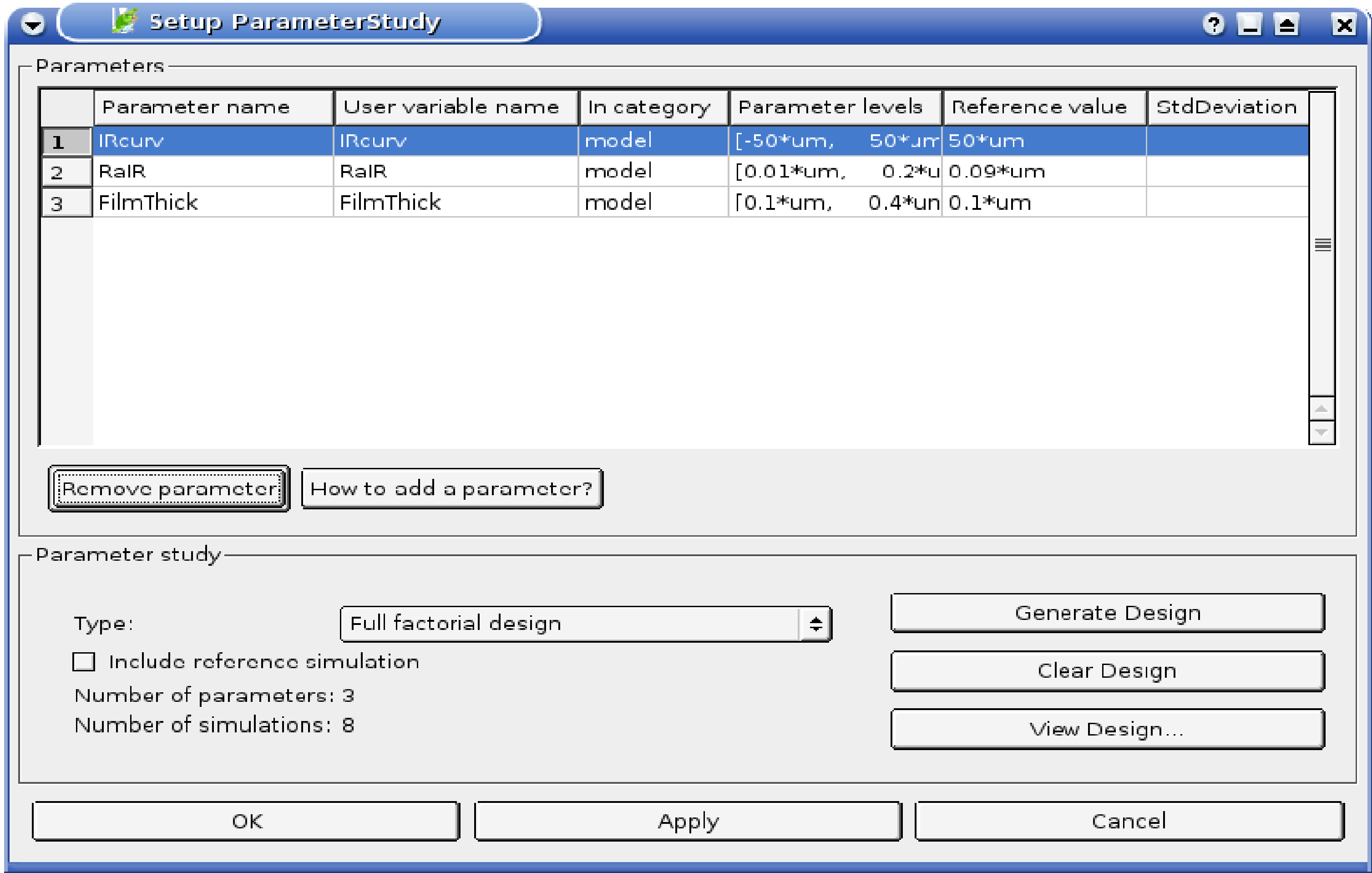
Sorting out confounding factors

To make sure we are not being fooled by confounded effects we run a full factorial with the top three factors:



Confounding...(cont.)

We first remove all parameters except the ones with top three effects according to the screening design...:



Confounding...(cont.)

Read the results into DoEBeast and again display the Pareto effects:

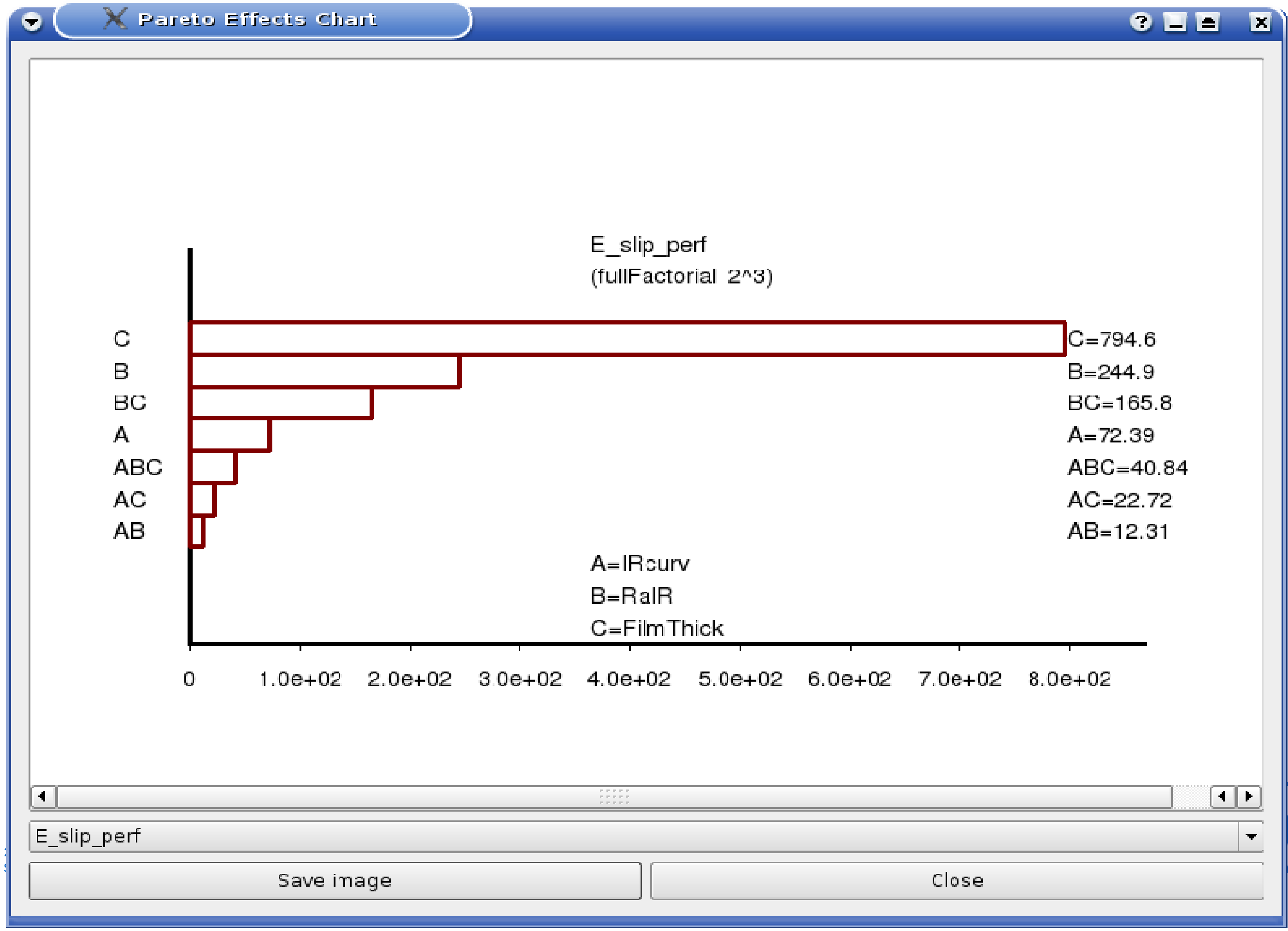
DoEBeast

File View Setup Help

Experiment	IRcurv	=IRcurv	RaIR	=RaIR	FilmThick	=FilmThick	h_wear_perf	E_slip_pe
Experiment set:/scratch/stefan/work/DoE/NewStart/DoETutorial/simpleSRB_dealiasing_fuf3_8								
simpleSRB_dealiasing_fuf3_8_PS_1	-0.00005	-5e-5	0.00000001	1e-8	0.0000004	4e-7	-4.10617850832296e-8	-2.06777270507
simpleSRB_dealiasing_fuf3_8_PS_2	-0.00005	-5e-5	0.00000001	1e-8	0.0000001	1e-7	-4.5152042105201e-8	-2.63302075195
simpleSRB_dealiasing_fuf3_8_PS_3	-0.00005	-5e-5	0.0000002	2e-7	0.0000004	4e-7	-4.04519795438318e-8	-2.09377734375
simpleSRB_dealiasing_fuf3_8_PS_4	-0.00005	-5e-5	0.0000002	2e-7	0.0000001	1e-7	-4.13939176269196e-8	-3.07225683593
simpleSRB_dealiasing_fuf3_8_PS_5	0.00005	5e-5	0.00000001	1e-8	0.0000004	4e-7	-4.04662507946796e-8	-1.91952124023
simpleSRB_dealiasing_fuf3_8_PS_6	0.00005	5e-5	0.00000001	1e-8	0.0000001	1e-7	-4.46522285812989e-8	-2.61188110351
simpleSRB_dealiasing_fuf3_8_PS_7	0.00005	5e-5	0.0000002	2e-7	0.0000004	4e-7	-4.00586657178792e-8	-2.05181762695
simpleSRB_dealiasing_fuf3_8_PS_8	0.00005	5e-5	0.0000002	2e-7	0.0000001	1e-7	-4.07141556024726e-8	-2.99404663085

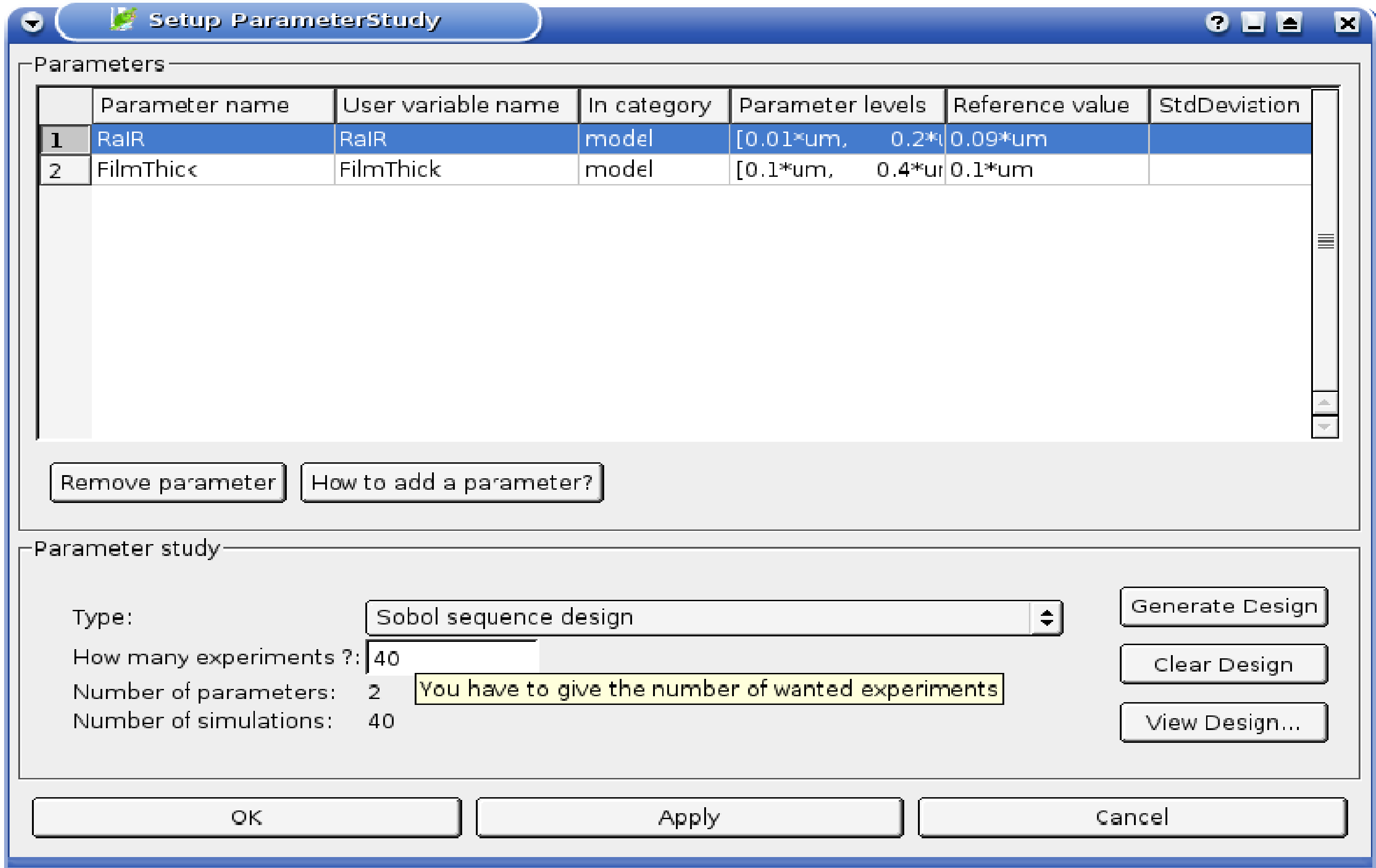
Confounding...(cont.)

Aha! *Ircurv* was confounded by the second order effect *RalR*FilmThick:*



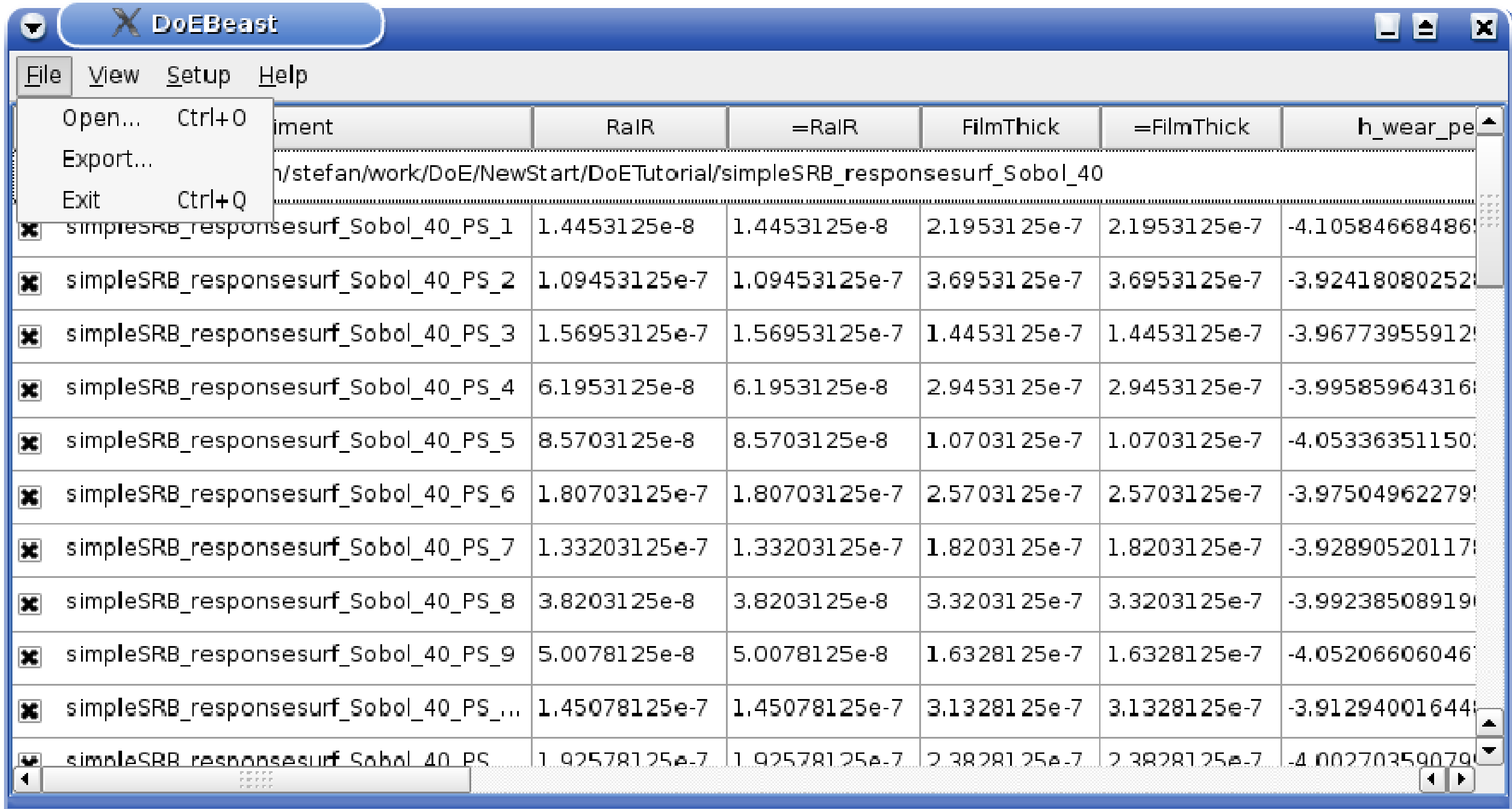
Optimising with response surface

Only two factors left. Let’s optimise the model with regard to them. Use a space-filling design (Sobol):



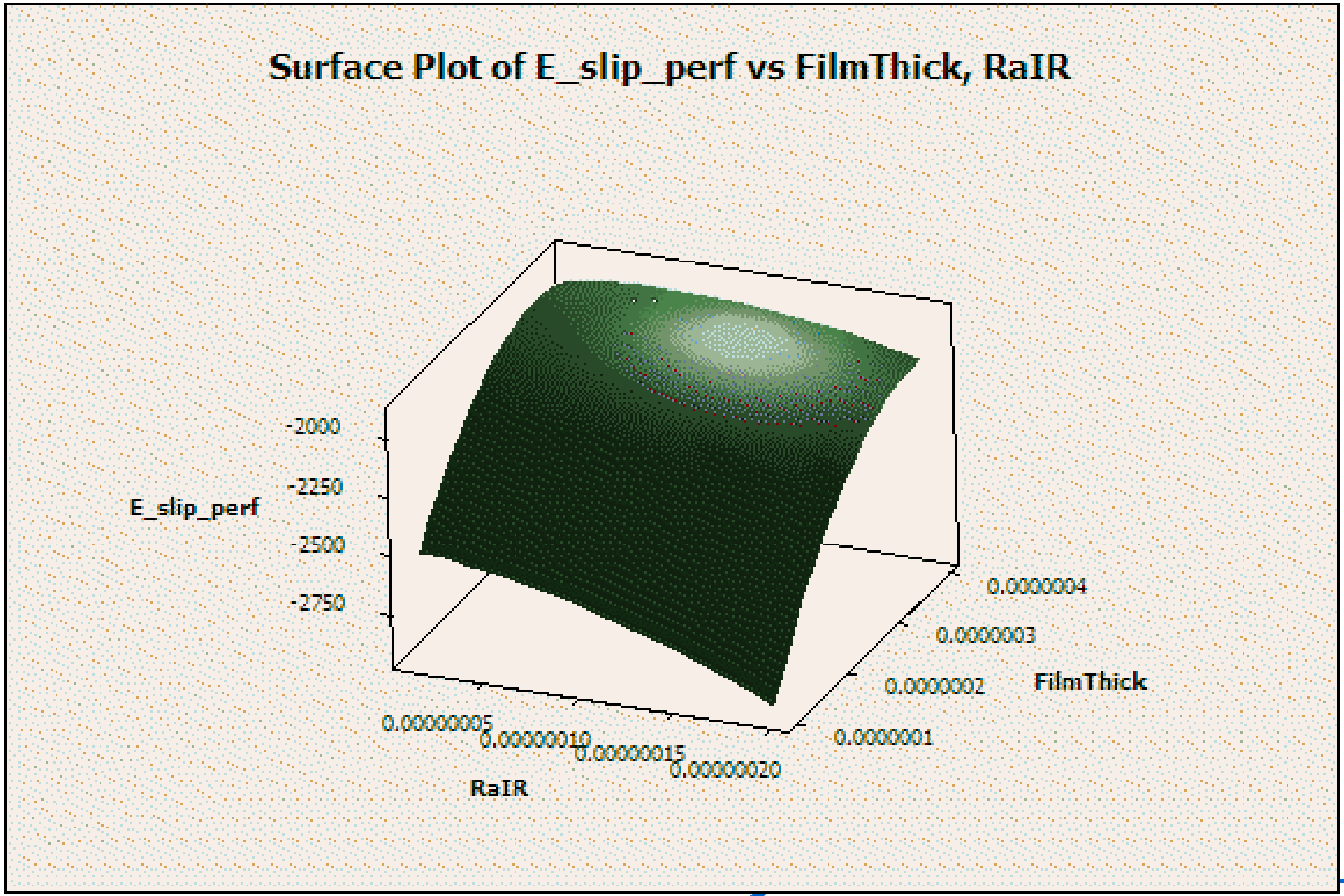
Optimising...(cont.)

Export the results to a file readable by Minitab:



Optimising…(cont.)

The response surface:



Sensitivity analysis:

If the user knows the standard deviations of his model parameters he can setup a design that lets DoEBeast compute approximations of the mean and standard deviations of output data.

Derivatives are computed as finite-differences.

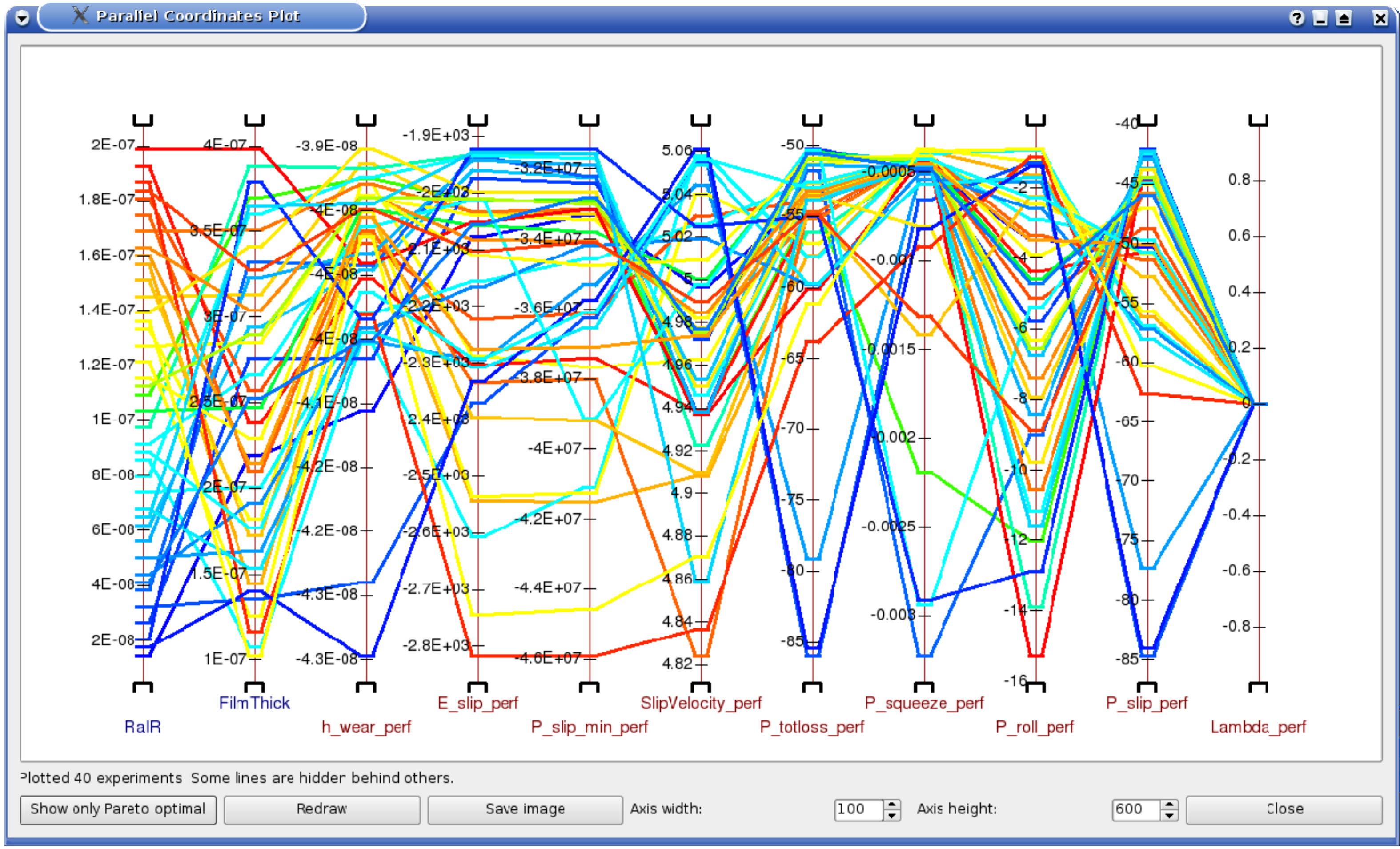
$$\mu_y \approx f_y(x_1, \ldots, x_n) + \frac{1}{2}\sum_{i=1}^{n} \frac{\partial^2 f_y(x_1, \ldots, x_n)}{\partial x_i^2}\sigma_i^2$$

$$\sigma_y \approx \sqrt{\sum_{i=1}^{n} \left(\frac{\partial f_y(x_1, \ldots, x_n)}{\partial x_i}\right)^2 \sigma_i^2}$$

Other features: Parallel coordinate plot

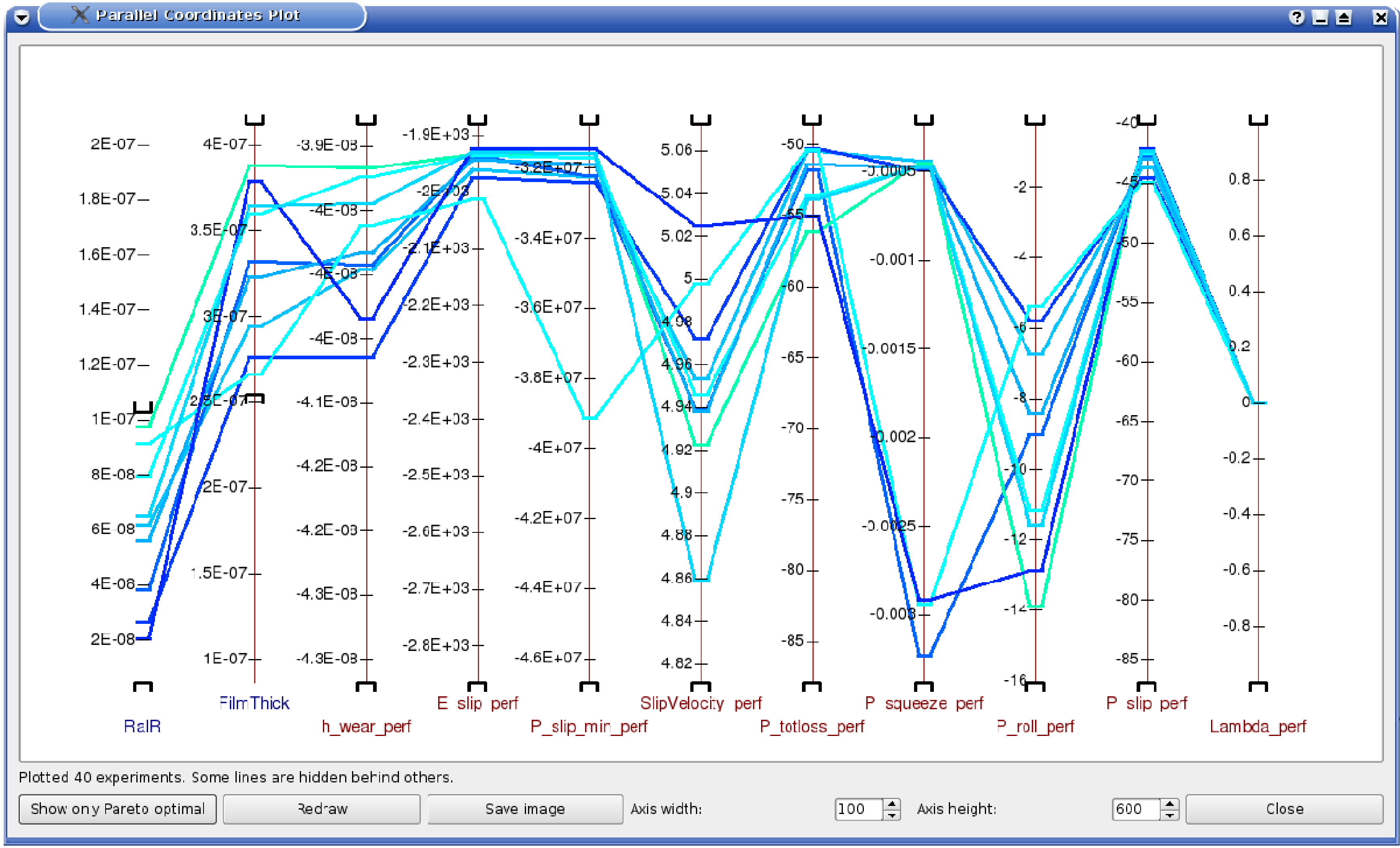
DoEBeast can plot results in several ways.

Parallel coordinate plot:



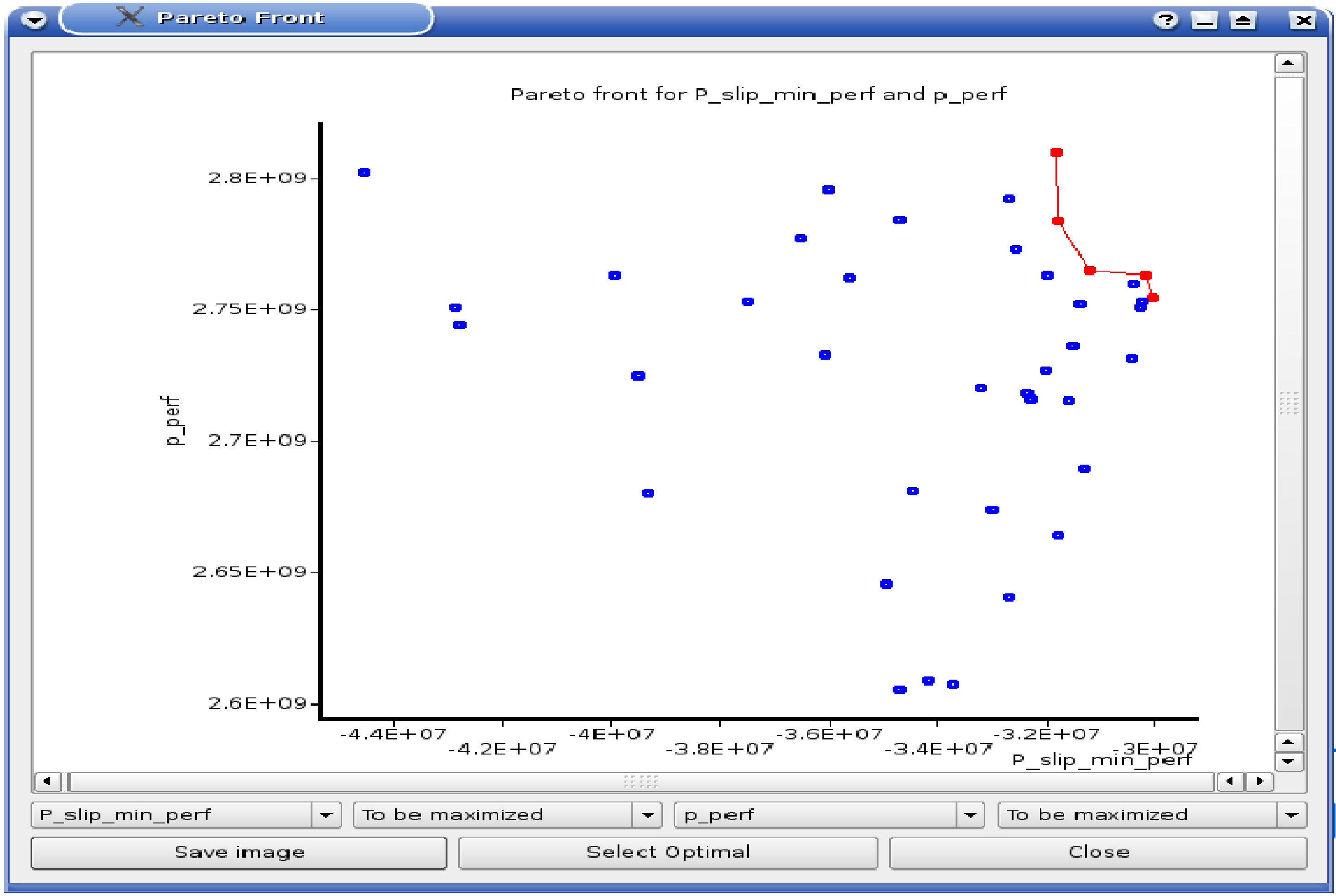
Parallel coordinate plot, cont ...

Restrict *FilmThick* and *RalR*



Other features: Pareto optimal plot

Pareto optimal front. Useful when more than one criteria is important:



Conclusion – Practical DFSS simulation

Reduce the number of parameters, i.e., screening designs.

Investigate confounding effects.

Do full DoE for remaining parameters (very few).

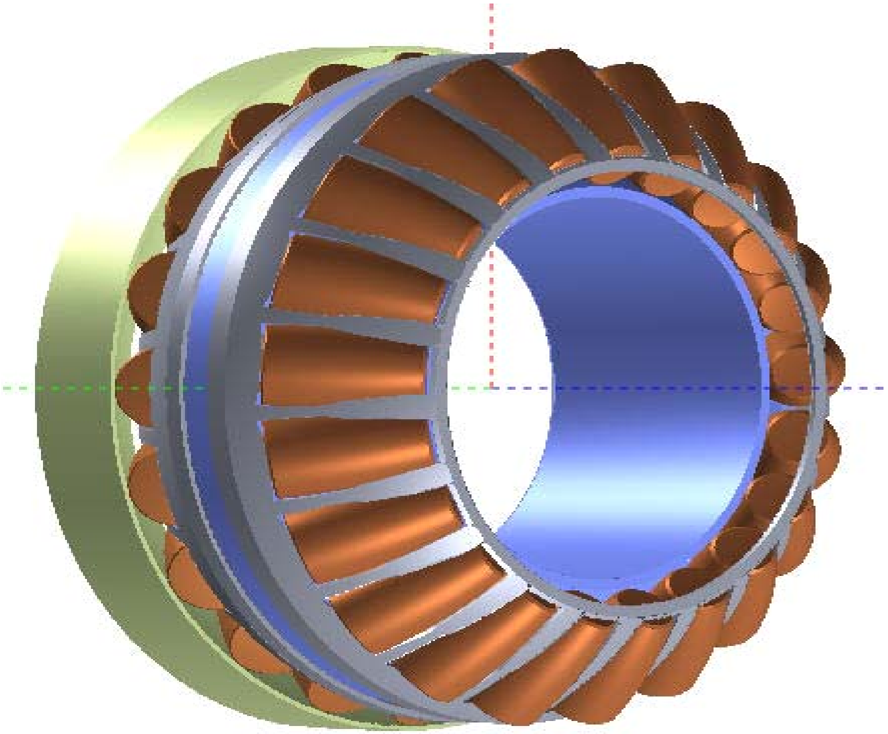
Investigate robustness.

SKF

3

Parallel Computation

Spherical Roller Thrust Bearing (SRTB)



DEA Cluster – 356 cores

1U rack nodes [76 cores]:
- 16 × Opteron 248 (single core 2.2GHz), 2GB memory
- 60 × Opteron 250 (single core 2.4GHz), 2GB memory

IBM Blade Centers [280 cores]:
- 3 × 14st IBM BladeServer HS21 XM
  - 2 × AMD Opteron 2218 (Dual core 2.6GHz) **[3*14*2*2 = 168 Cores]**
  - 4GB RAM **[168GB]**
- 1 × 14st IBM BladeServer HS21 XM
  - 2 × Intel XEON E5420 (Quad core 2.5GHz) **[14*2*4 = 112 Cores]**
  - 16GB RAM (8 × 2GB) **[224GB]**

Neolith cluster at NSC – 6440 cores

Hardware and Performance:

• 805 Nodes (HP ProLiant DL140 G3)
  - •Two Intel Xeon E5345 Quad Core Processor 2.33GHz per Node
  - •16GB or 32GB RAM per node

•Infiniband ConnectX interconnect

•Combined peak performance of 60 Tflops

Software:

•Operating System: CentOS 5 x86_64

•Resource Manager: SLURM

•Scheduler: MOAB

•MPI: OpenMPI and Scali MPI

NVIDIA FERMI a future platform?

Hardware and Performance:

- 16 Streaming Multiprocessors (SM)
  - 32 CUDA cores per SM
  - 4 Special Function Units per SM
  - 64 KB Shared Memory/L1 Cache
- ECC Memory Support
- Single Precision Floating Point Capability: 512 FMA ops/clock
- Double Precision Floating Point Capability: 256 FMA ops/clock
- Support for up to 16 concurrent Kernels

4

Summary

Summary

Use simulation early in the product development process.

The Six Sigma/DFSS effort stimulate use of analytical tools.

Heavy simulations & Parametric studies:

- Eliminate parameters with screening designs.
- Find optima with space filling designs.
- Check robustness in design points.

SKF®