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# Optimization of robustness as contribution to early design validation of kinematically-dominated mechatronic systems regarding automotive needs

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# Agenda

(1) Kinematic systems

(2) Early design stage in the automotive industry

(3) Robustness – overview

(4) Robustness of kinematic systems

(5) Optimization process

(6) Conclusions

# Kinematic systems

- General: Large movements (translation & rotation) of inertia-afflicted bodies

- Examples of the automotive industry:

- *automatic tailgates* *window lifters* *retractable tops*

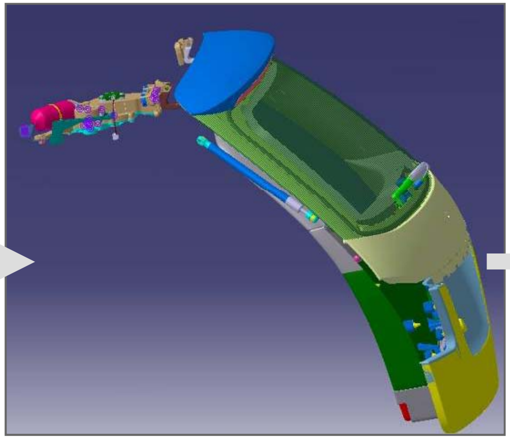
# Kinematic systems – Example automatic tailgate

→ Simulation by Multi-Body System Dynamics (MBS)

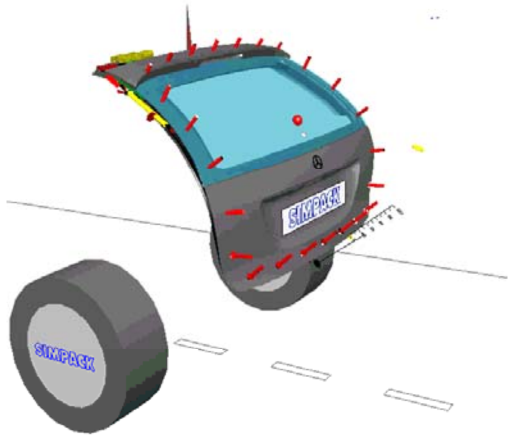
Use-cases

- $\vartheta$
- $\alpha_1, \alpha_2$
- manually operated
- interim position

Physical Mock-up



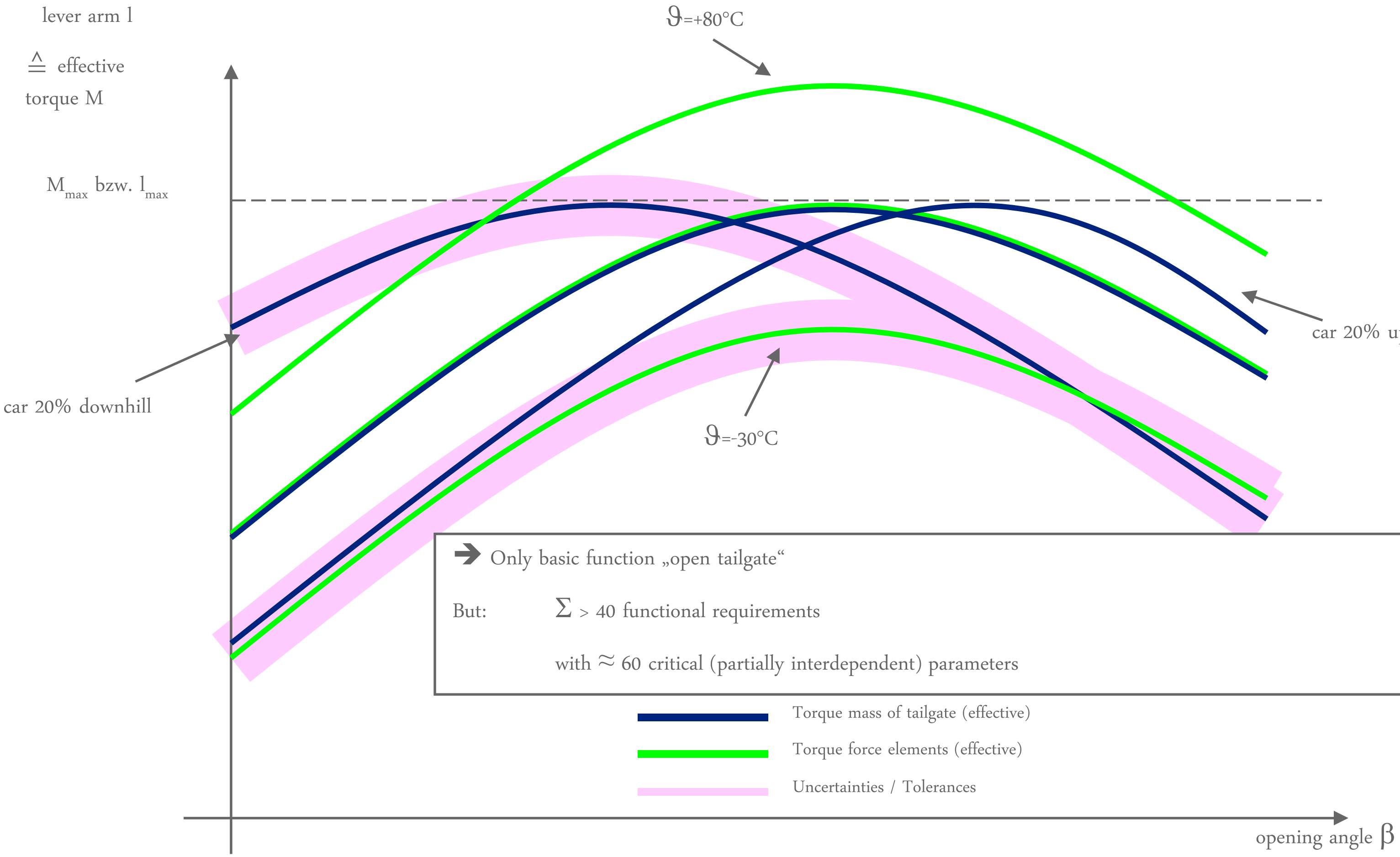
Digital Mock-up




Multi-Body System Simulation

# Special challenges of kinematics

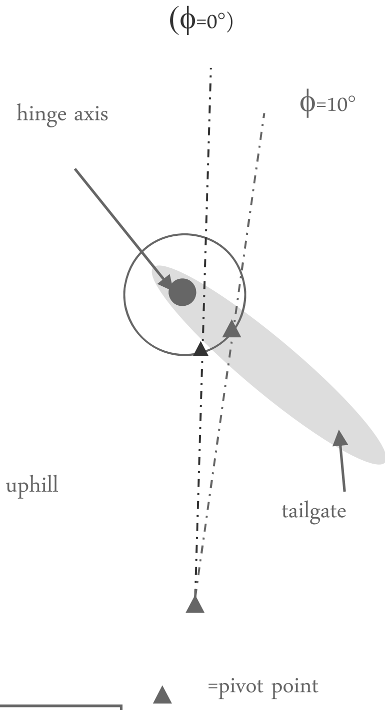
## Basic function „open tailgate "




➔ Only basic function „open tailgate"

But: $\Sigma$ > 40 functional requirements

with ≈ 60 critical (partially interdependent) parameters



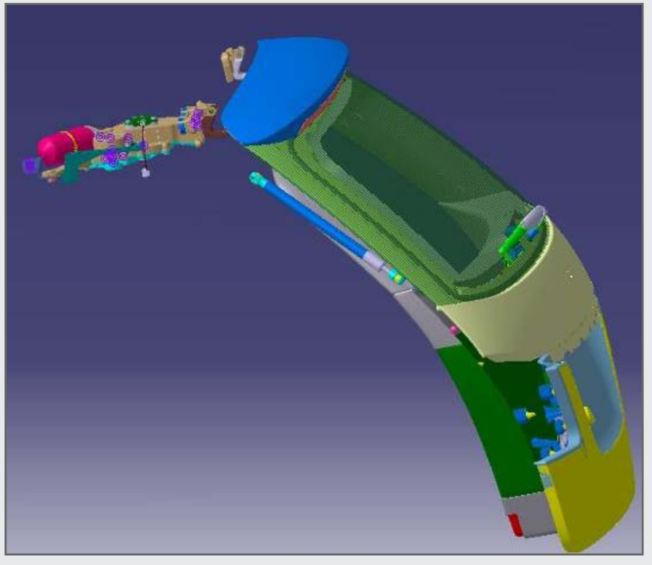
# Status quo

**Design of automatic tailgate systems**

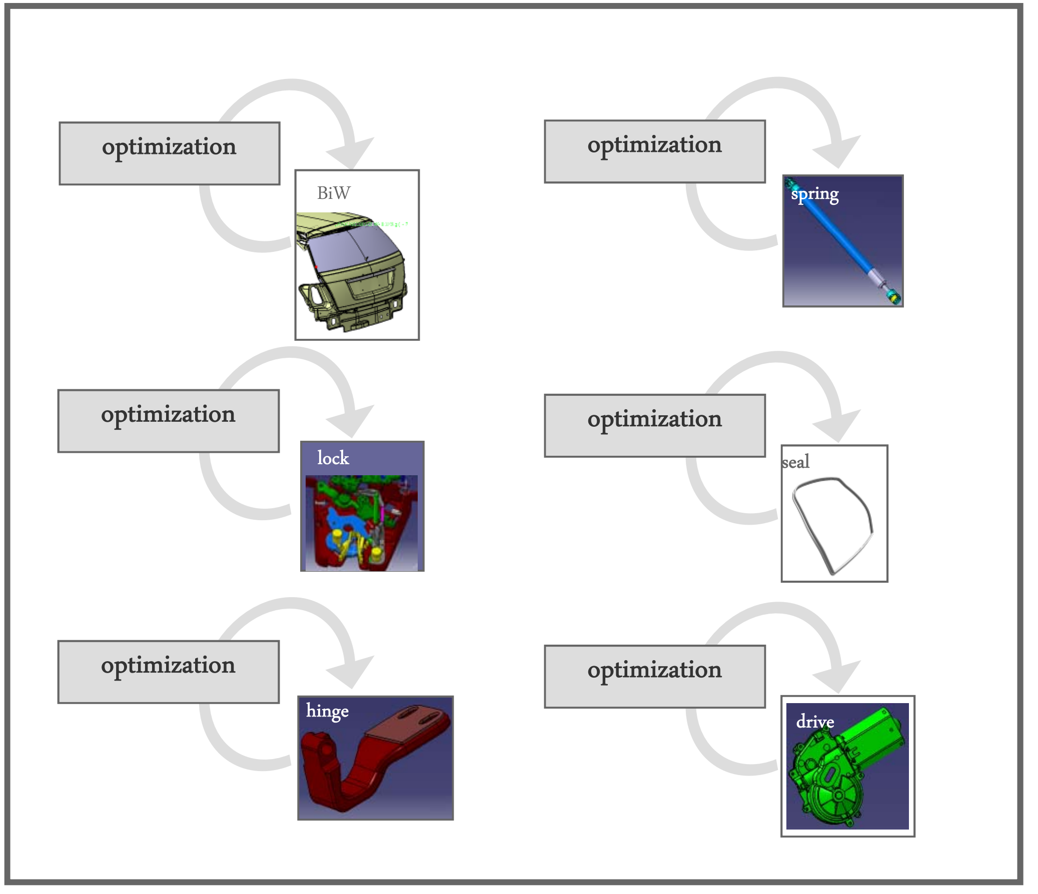
→ Solitaire consideration of components

→ Bad behavior during hardware testing results in optimization of components

→ No systemic knowledge about interaction and influence on target functions of entire system



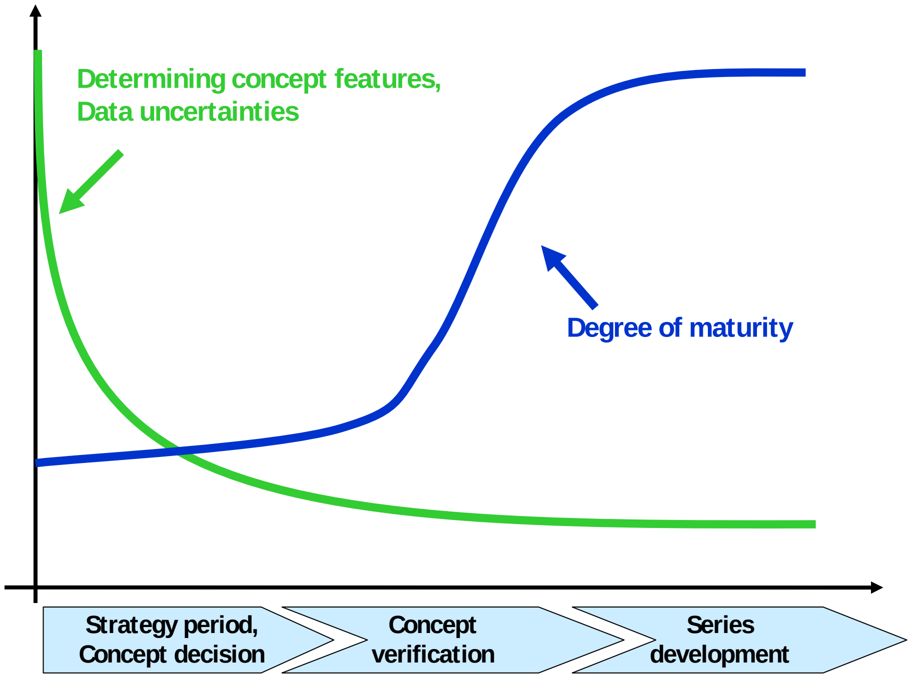
Component-orientated system design



# Early design stages – basic dilemma

Concept decisions have to be made

- early
- despite low degree of maturity (styling etc.)
- despite high data uncertainties




Additional challenges for automotive kinematic systems

+ Supplier is often responsible for system (→evidence only possible through hardware testing)
+ Shared development
+ Vehicles containing kinematics often derivates of a platform (e.g. retractable tops)

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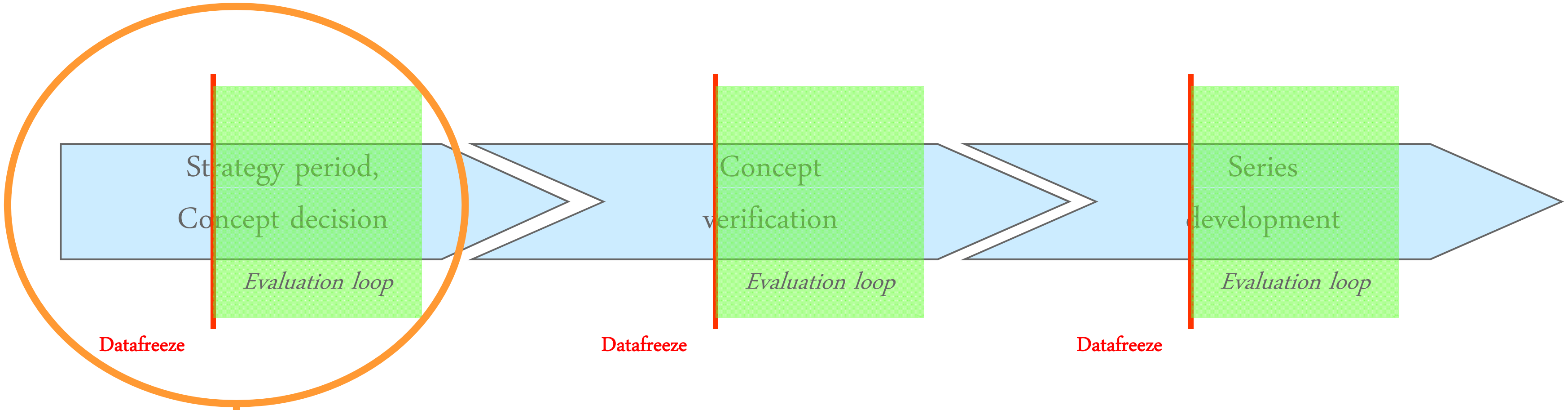
## Early design stages in the automotive industry




**Competing concepts are evualated with input of datafreeze**

- Input often based on predecessor car
- Input afflicted with uncertainties due to
  - Styling process influence (management decisions)
  - Design process influence (data fully / partially unavailable)
  - CAD method influence (hybrid, complex data; input differs from reality)
- Evaluation loops often don't contain variation possibilites of input data
- Evaluation of different concepts based on one datafreeze

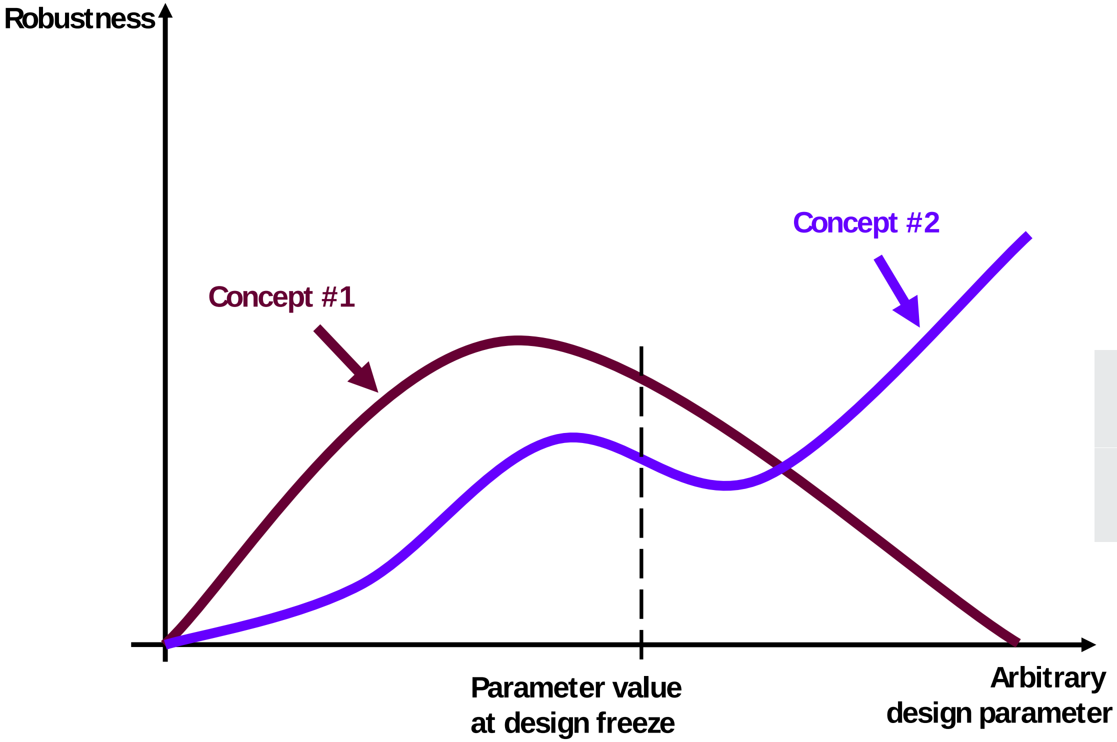
➔ Simulated concepts arguably operate with suboptimal input parameters

# Target: Optimization of kinematics behavior

Basic questions:

*„How do we ensure that the evaluated concepts operate with concept-specific optimal parameters?“*

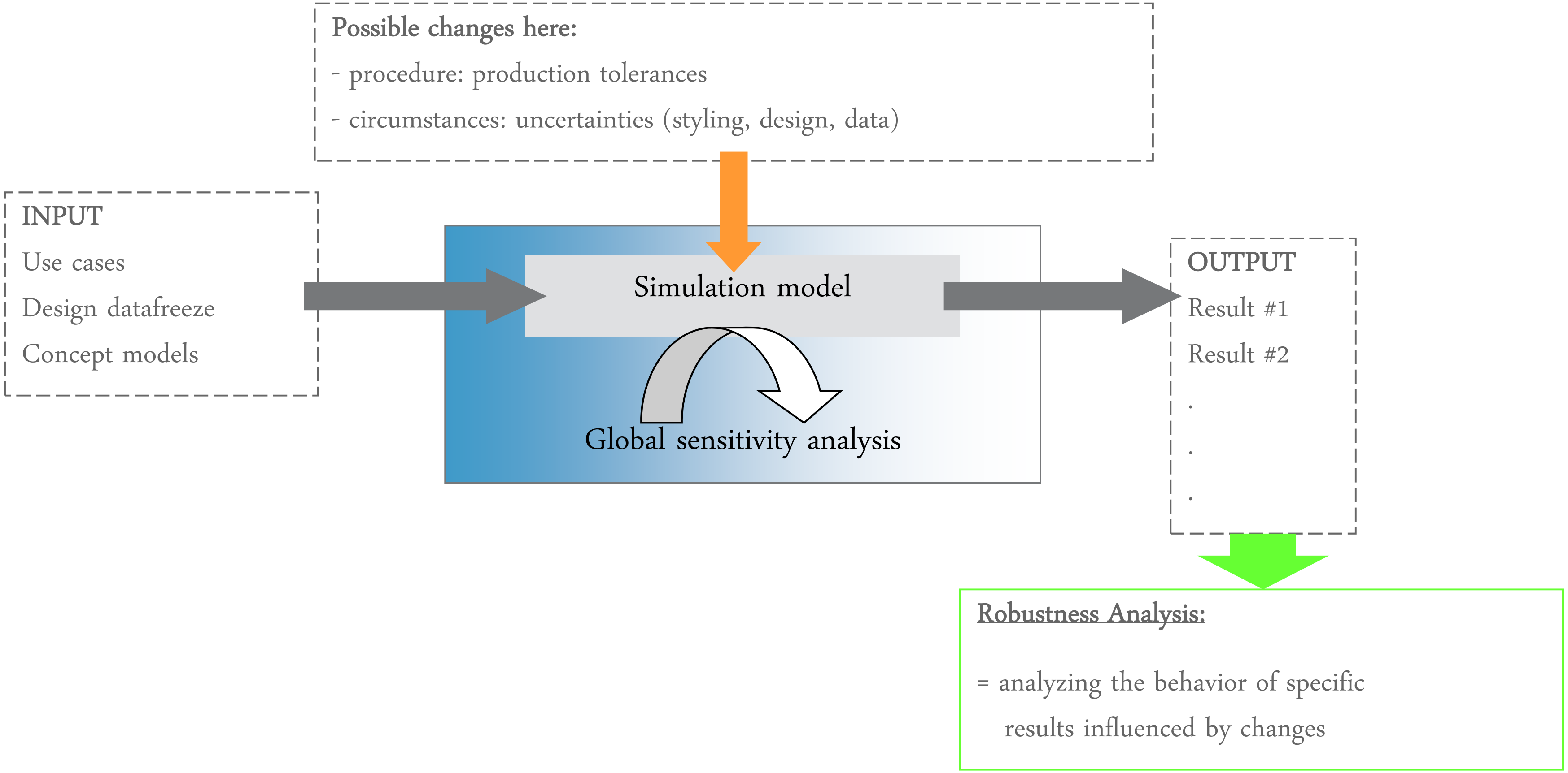
*„What are optimal parameters for kinematic systems?“*



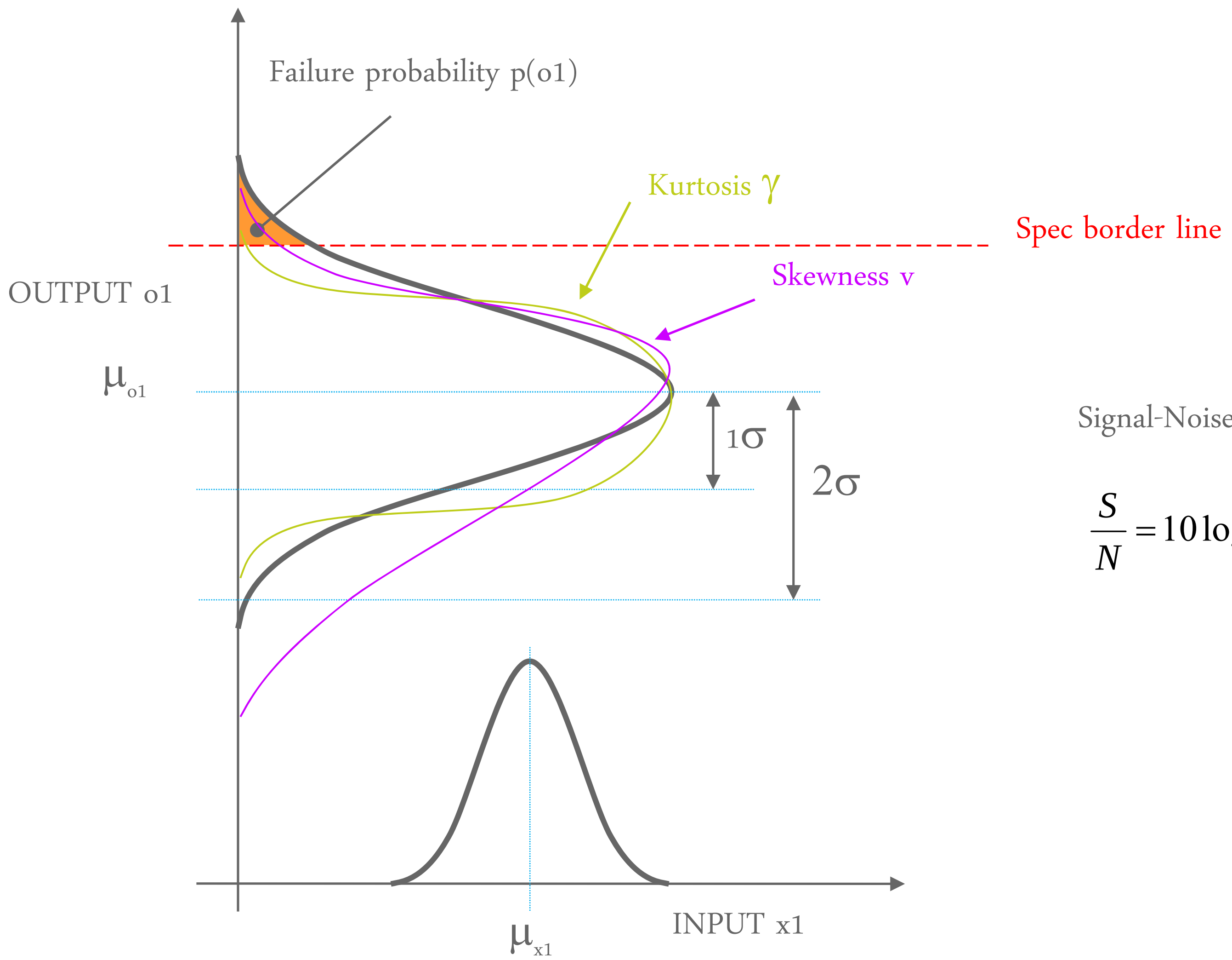

→ Concepts perform best if they are maximal robust against uncertainties brought by early design stage problems

# Robustness analysis – overview

*„Robustness is the quality of being able to withstand **changes in procedure or circumstances**"*



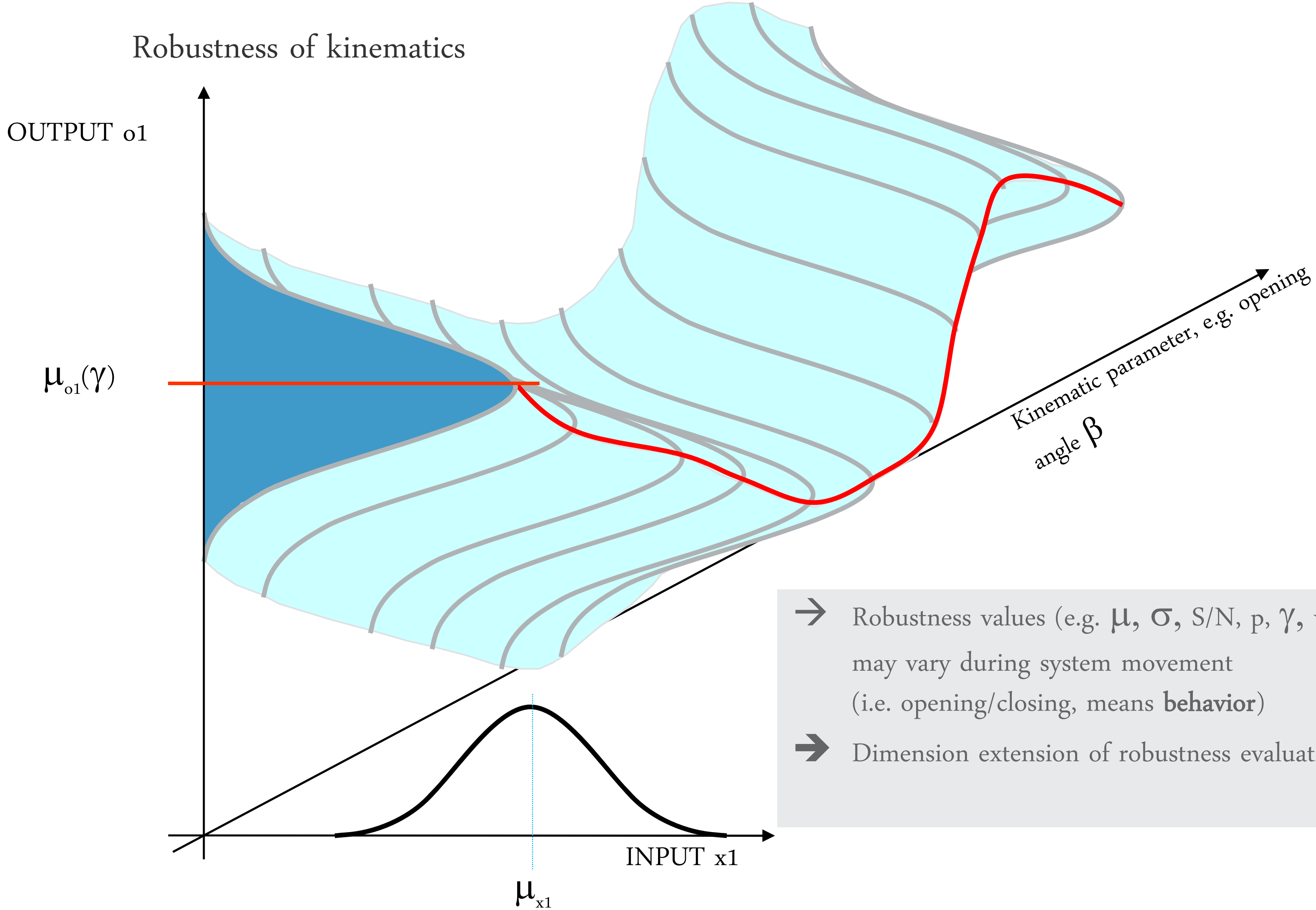
# Robustness values – basics




Signal-Noise-Ratio formulas, e.g.:

$$\frac{S}{N} = 10 \log \frac{\mu^2}{\sigma^2} \quad \text{or} \quad \frac{S}{N} = 10 \log \frac{\mu^2}{(2\sigma)^2}$$

Robustness of kinematics



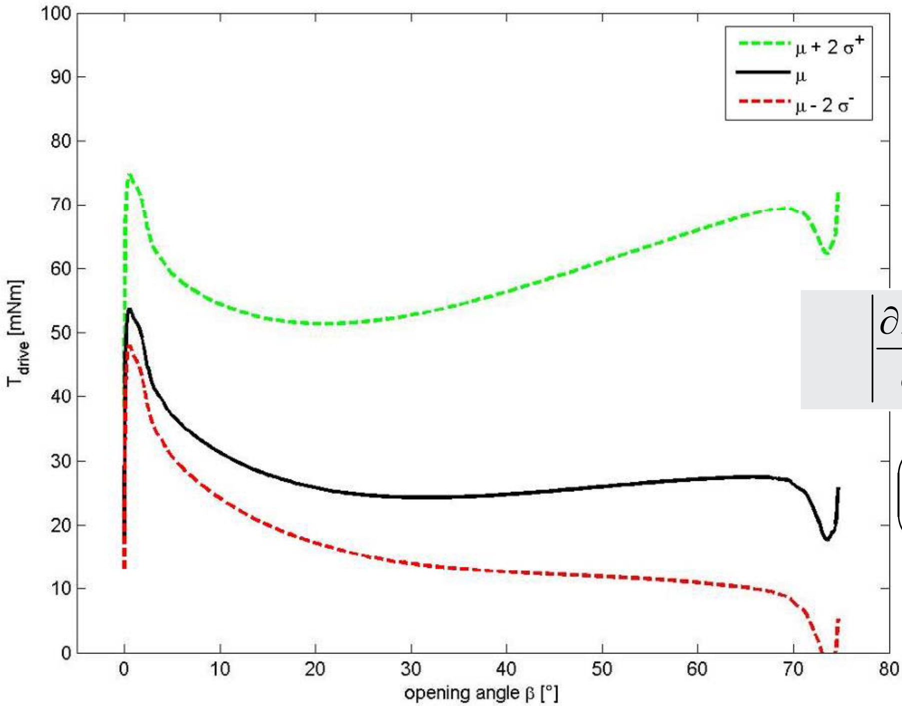

→ Robustness values (e.g. $\mu$, $\sigma$, S/N, p, $\gamma$, v) may vary during system movement (i.e. opening/closing, means **behavior**)

→ Dimension extension of robustness evaluation

# Robustness analysis of behavior

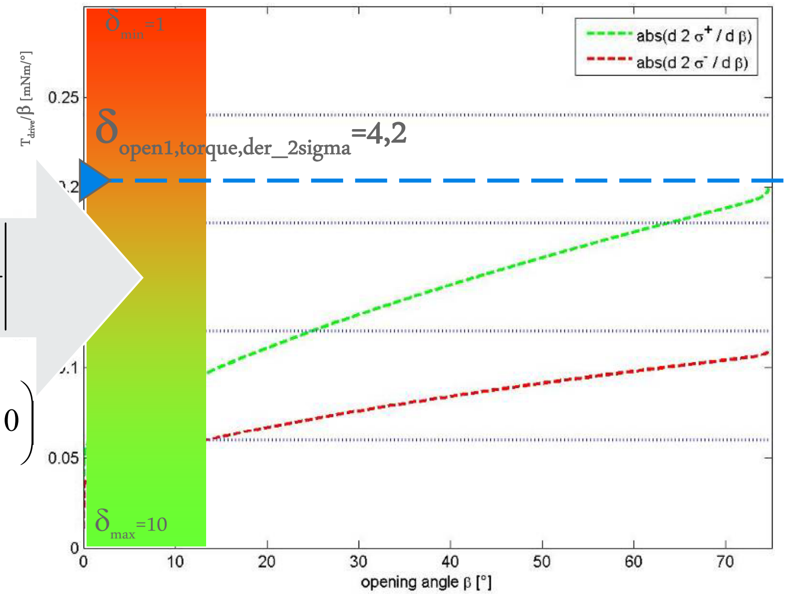
Example: Necessary drive torque (for basic function „open tailgate“)

→analyzing standard deviation 2σ



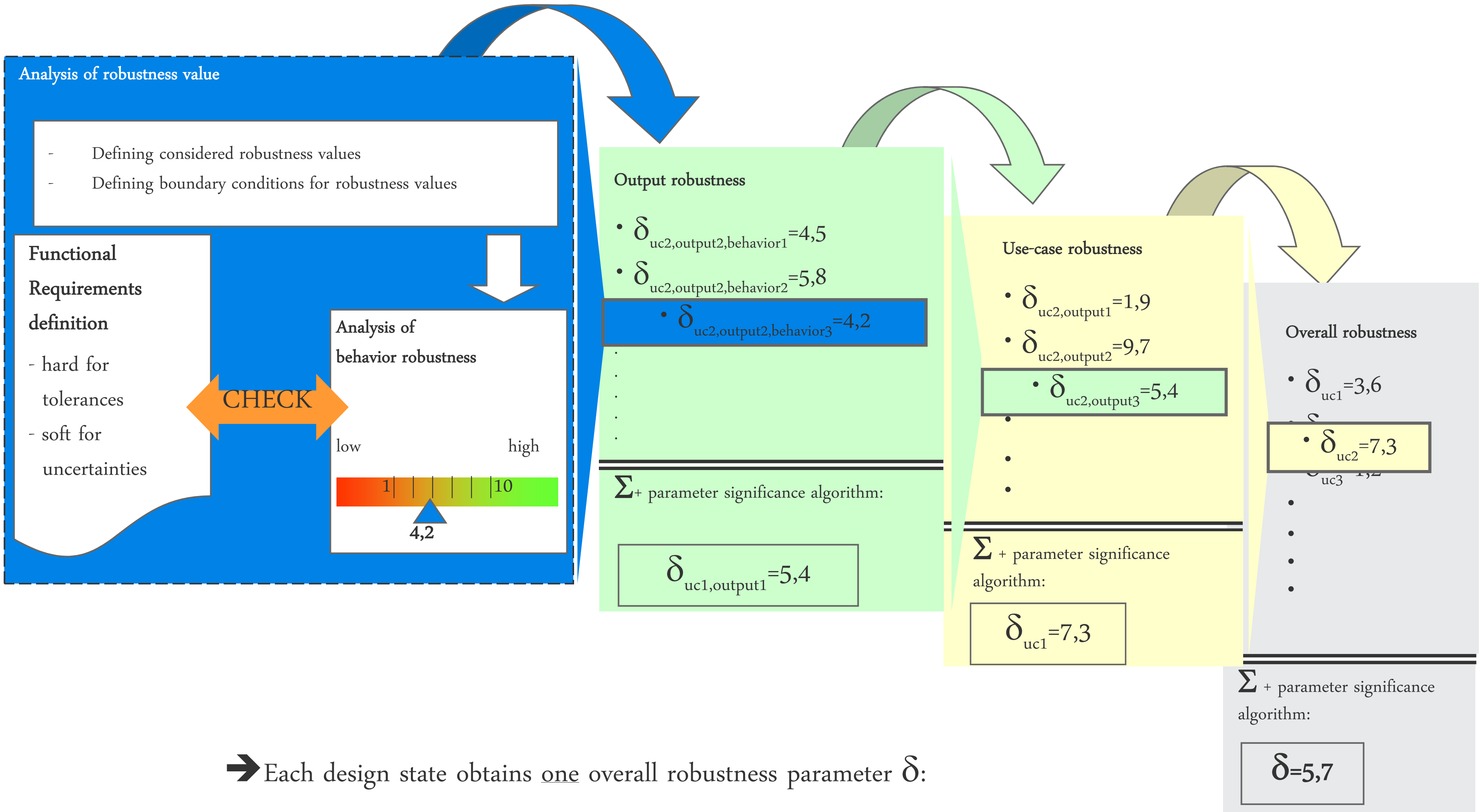

$$\left|\frac{\partial 2\sigma^{+}}{\partial \beta}\right|, \left|\frac{\partial 2\sigma^{-}}{\partial \beta}\right|$$

$$\left(\frac{\partial \nu}{\partial \beta} \neq 0, \frac{\partial \gamma}{\partial \beta} \neq 0\right)$$



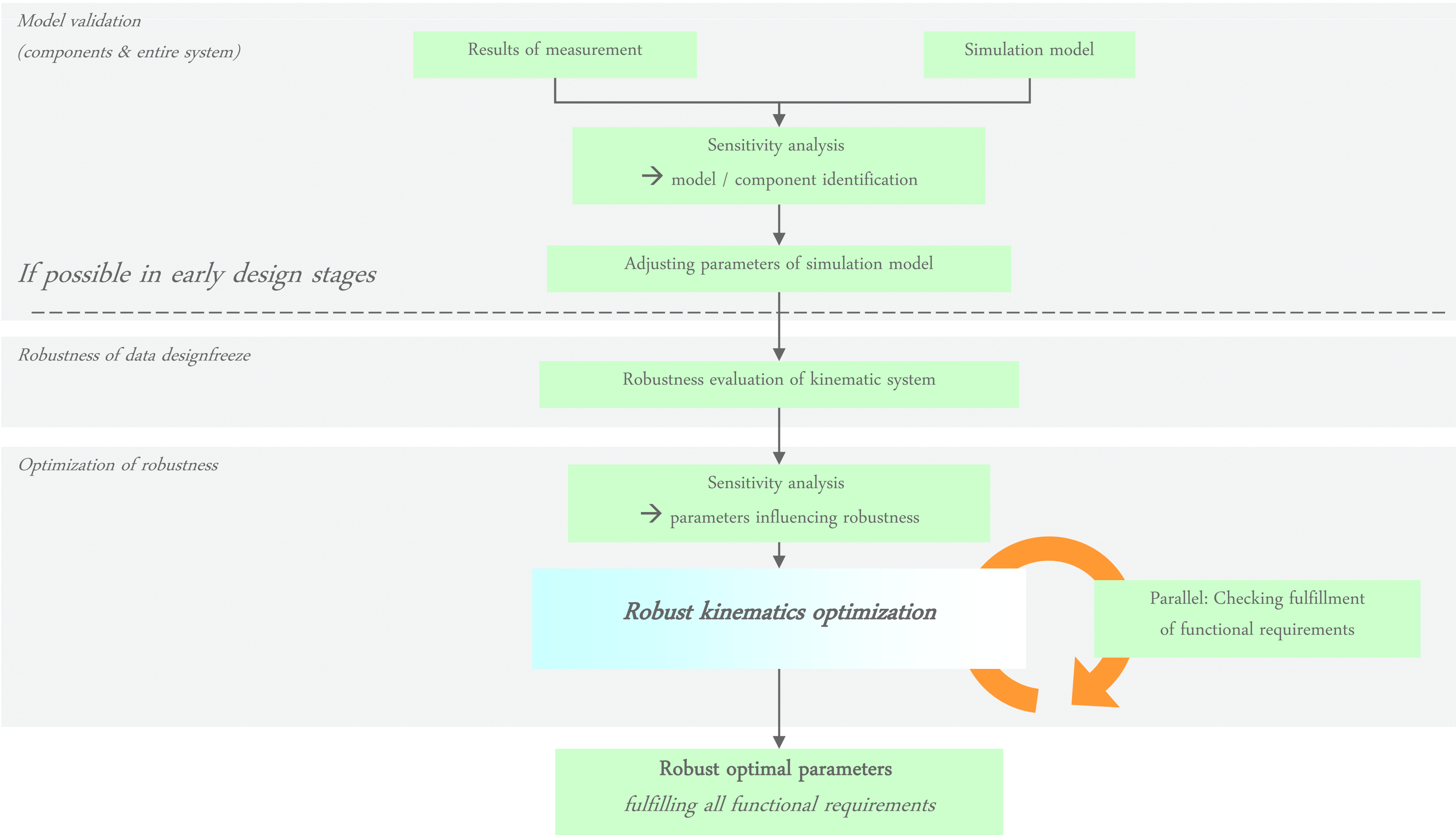

→ Quantification of behavior robustness parameters permits overall analysis of kinematic system concepts

# Robustness evaluation of kinematics




➔Each design state obtains one overall robustness parameter $\delta$:

# Optimization process



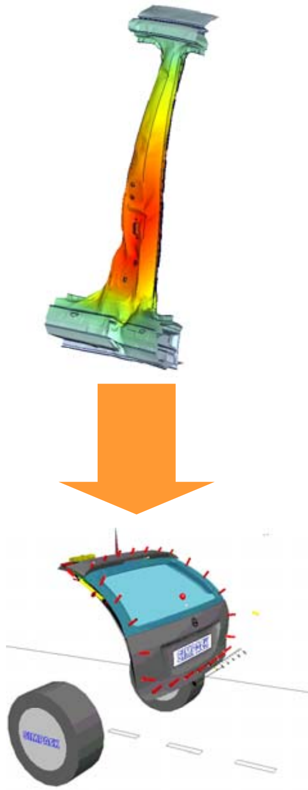
# Robust kinematics optimization RKO

Basic idea: variance-based Robust design optimization RDO

→ desensitize (~2σ) design through RDO, often by varying part design *(e.g. sheet thickness of b-pillars for influence of scattering material parameters for crash results, usually FEM-dominated)*

Adopting Robustness evaluation methods for kinematics on RDO

➔ Robust kinematics optimization **RKO**



RDO

RKO

Special challenge: Variation possibilities of kinematic system design parameters

- not included in data of OEM-designfreeze by default (e.g. room for kinematic points)
- not included in concept models of suppliers by default (e.g. spring forces, drive specifics, etc.)
- usually estimated on employee level (possibly leading to management / responsibility problems)

→ Standardization / methodology necessary (for supplier & OEM)

# Conclusion

- Early design stage optimization of kinematic systems needs complex simulation routines
- Systematic consideration of uncertainties evident for early investigation of supplier-offered concepts for kinematic systems
- Early Optimization of robustness against uncertainties increase validity of concept decisions and automotive styling insensitivity
- Standardized process (RKO) enables different concepts to be evaluated against each other rapidly