



ITUKALEIDOSCOPE

NANJING 2017

Challenges for a data-driven society

Advanced data enrichment and data analysis in manufacturing industry by an example of laser drilling process

M.Sc You Wang

RWTH Aachen University & Cluster of excellence

you.wang@ilt.fraunhofer.de

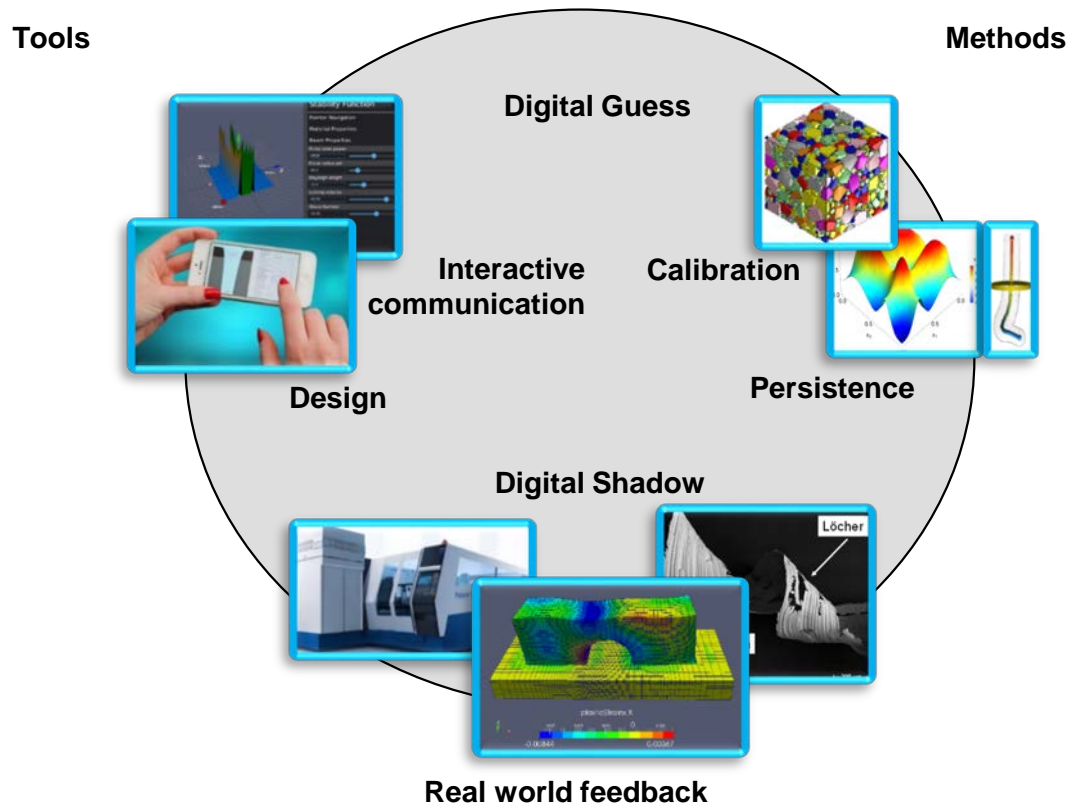


Nanjing, China
27-29 November 2017





Background: Internet of Production

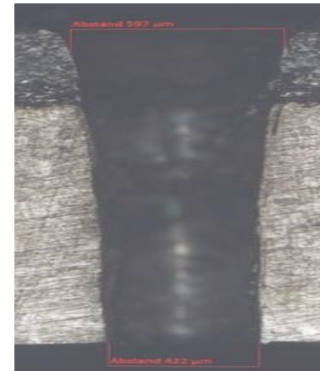




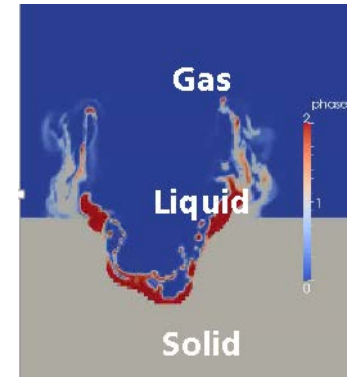
- Introduction of sparse data problems in manufacturing industry
 - Complicated Multi-physical processes
 - Multidimensional Domain Space
 - Limited Number of Experiments
 - Time consuming global numerical simulation

RQ: How to enrich sparse data to become dense enough for design?

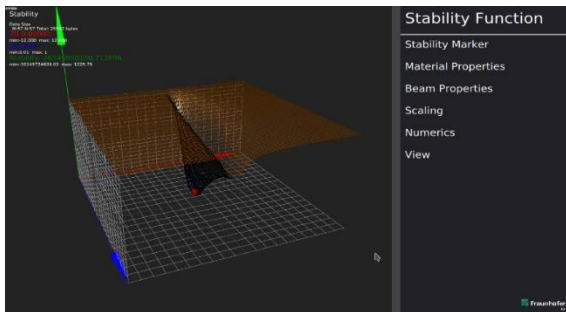
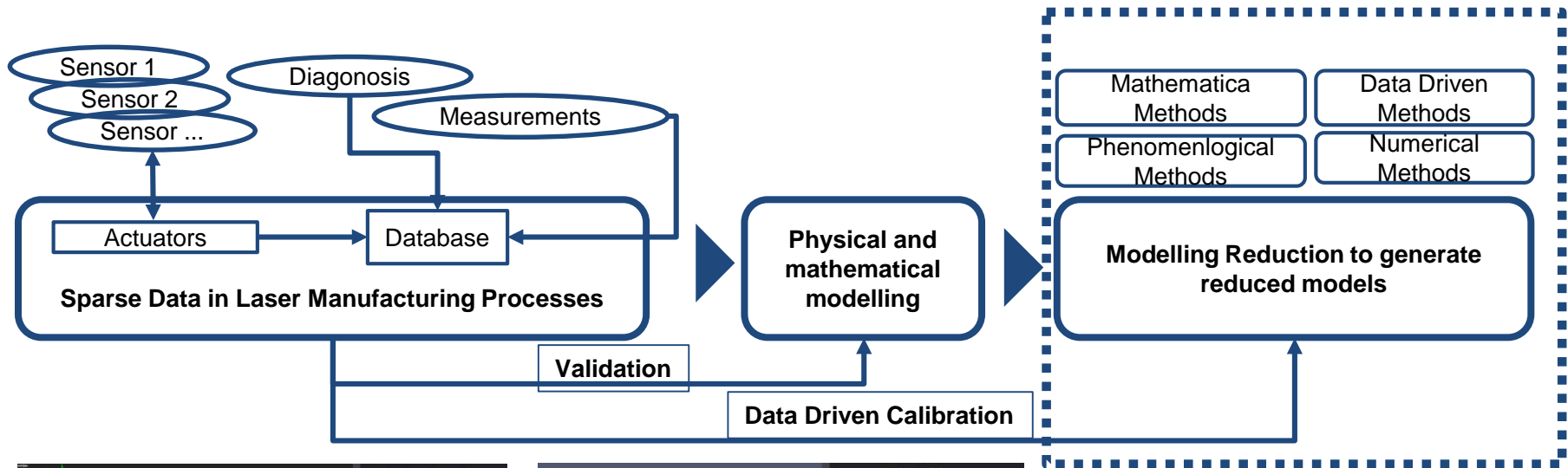
Experimental evidence



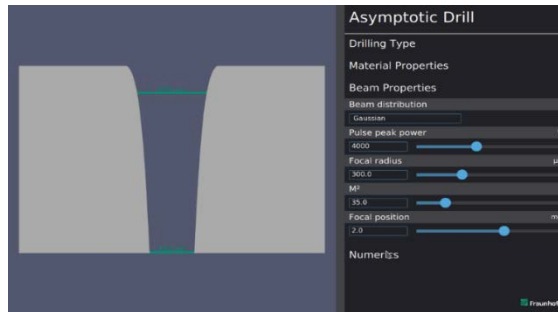
Numerical simulation



Data is sparse !



Stability Cutting App



Asymptotic Drill App

Digitalization---“Customer simulation Tool”





- Introduction of some model reduction techniques

Phenomenological Model Reduction

- Experience and Experimental Observation ...

Mathematical Model Reduction

- Asymptotic Analysis: Time Scale Separation,
- Singular Perturbation...

Numerical Model Reduction

- Proper Orthogonal Decomposition POD ...

Data Driven Model Reduction

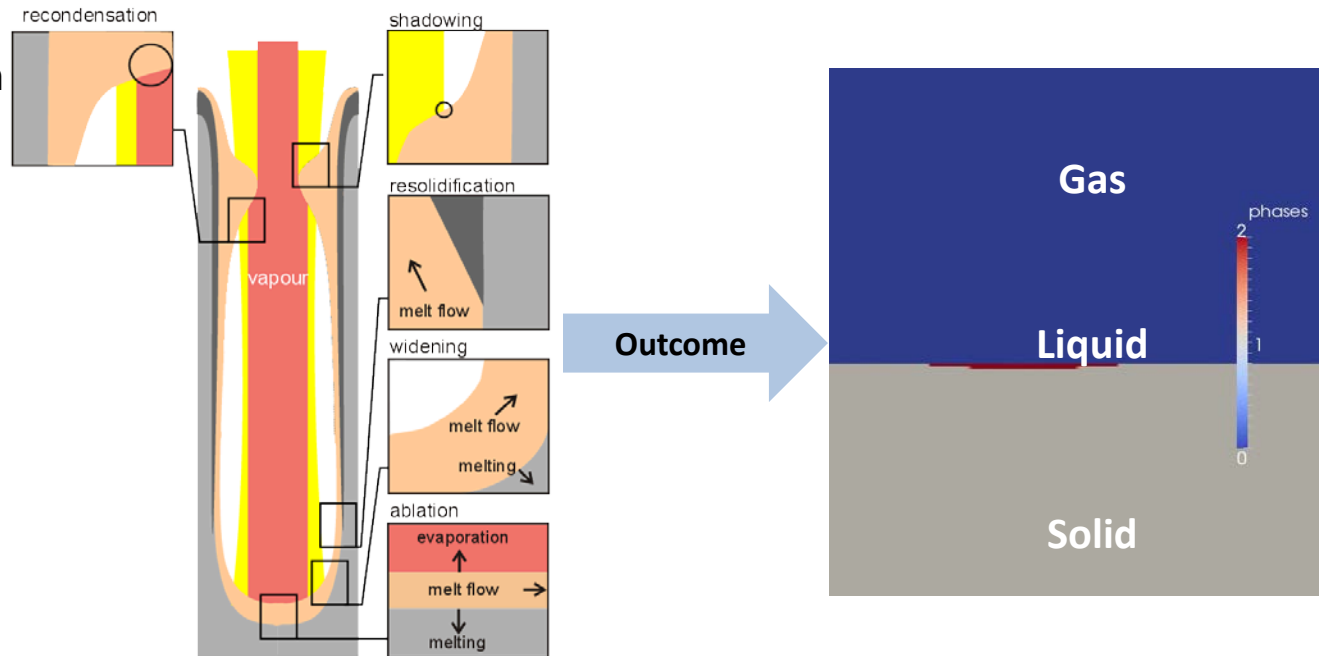
- Design of Experiment DoE ...
- Meta modelling...
- „Digital Guess“ – Interpolation of sparse data



Example: laser drilling process

Process Phenomena and coupling of many subprocesses

- Heat Conduction
- Melt flow
- Heat transport
- Evaporation
- Resolidification
- Gas flow





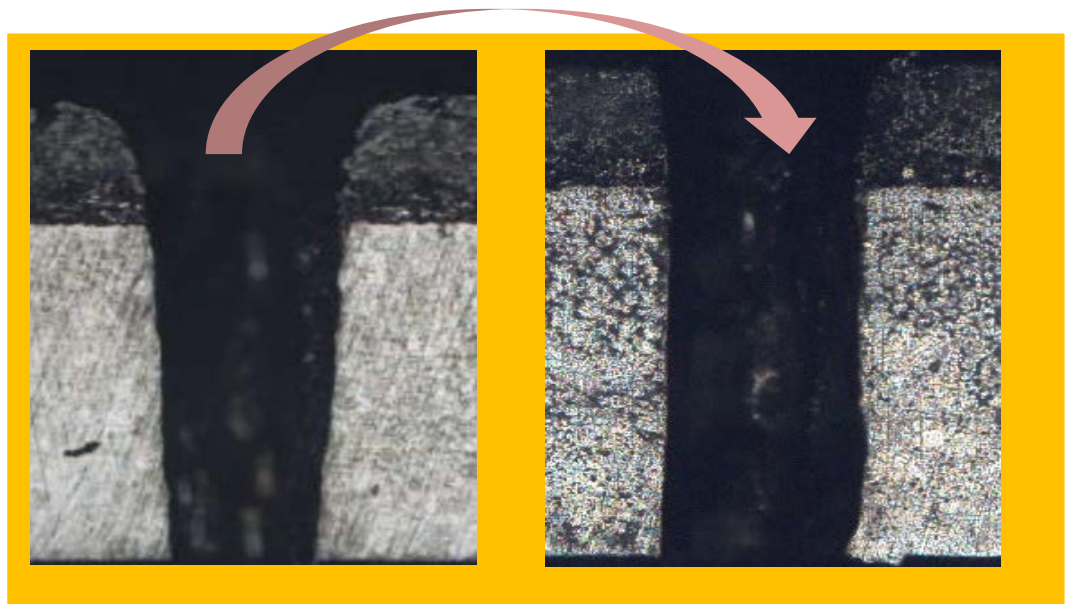
Asymptotic laser drilling

Research Question:
Objectives:

Drilling hole free of taper: $Conicity=1$

1. Minimize Conicity
2. Understand parameter effects (5-dimensional)

$$Conicity = \frac{Width_{Top}}{Width_{Bottom}}$$



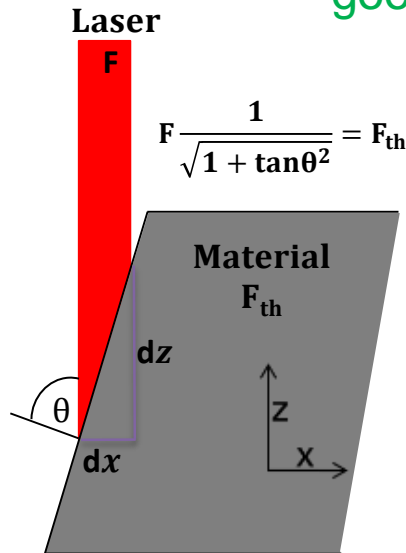


Reduced model – asymptotic drill

State of the Art – implicit knowledge

Innovative – explicit knowledge

Requirement: **Fast and Frugal Models with good solvability and strongly simplified error control**



Long time limit – Asymptotic Drill:
 Ablation occurs when the absorbed fluence reaches the threshold fluence of the material

$$F \cos \theta = F_{th}$$

$$\frac{dz}{dx} = \begin{cases} \sqrt{\left(\frac{F}{F_{th}}\right)^2 - 1} & \text{if } F \geq F_{th} \\ 0 & \text{if } F < F_{th} \end{cases}$$

ODE!!
 Solvability

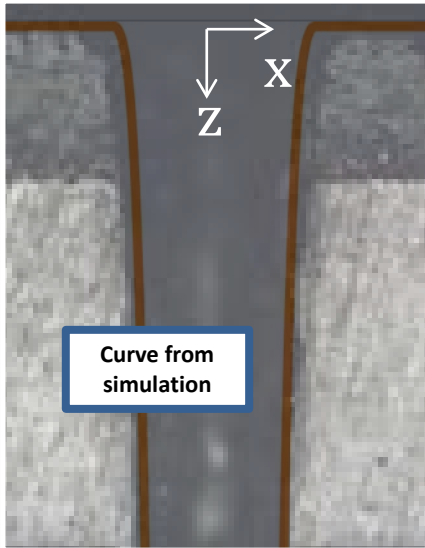
Available range from micro-second pulse to longer pulse laser

Reduced model makes sparse data expand to dense data

Model Validation

relative error
 3.58%-5.8%

$$\frac{dz}{dx} = \begin{cases} \sqrt{\left(\frac{F}{F_{th}}\right)^2 - 1} & \text{if } F \geq F_{th} \\ 0 & \text{if } F < F_{th} \end{cases}$$



Simulation:
 Entry diameter:
 650 μm
Experiment:
 Mean value hole
 entry diameter :
 669 ± 26 μm

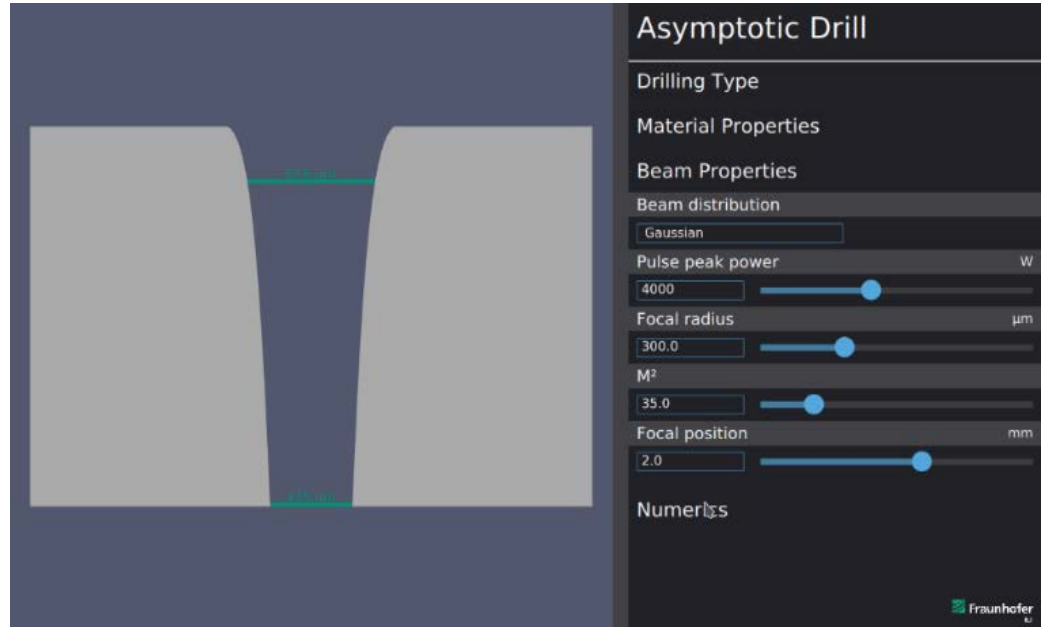
Simulation:
 Exit diameter:
 510 μm
Experiment:
 Mean value hole
 exit diameter:
 497 ± 19 μm

Sparse data



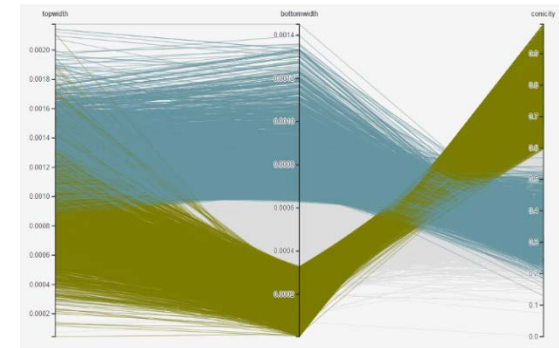
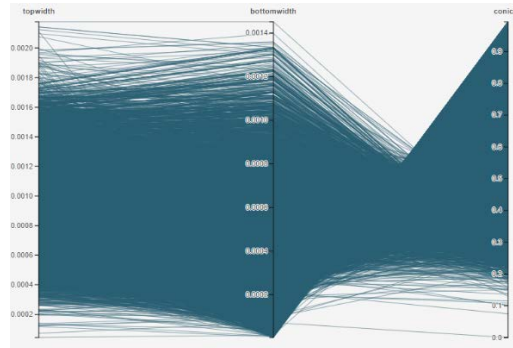
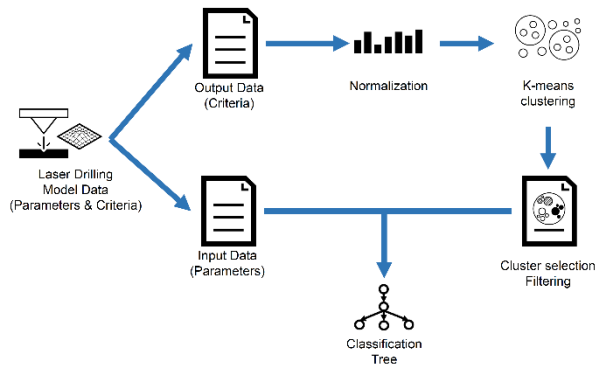
Dense data !

„Digital Guess“
Customer Simulation Tool
 Fast & Frugal Simulation
 calculation time << 1 second
 Real time level!

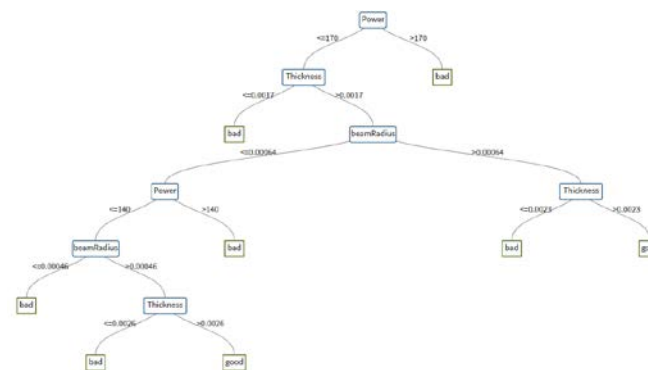




- Data analysis

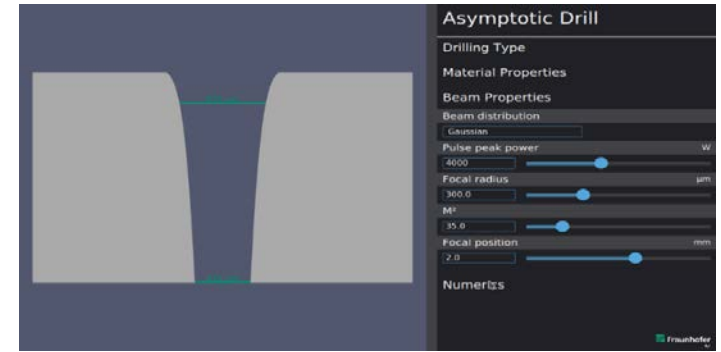
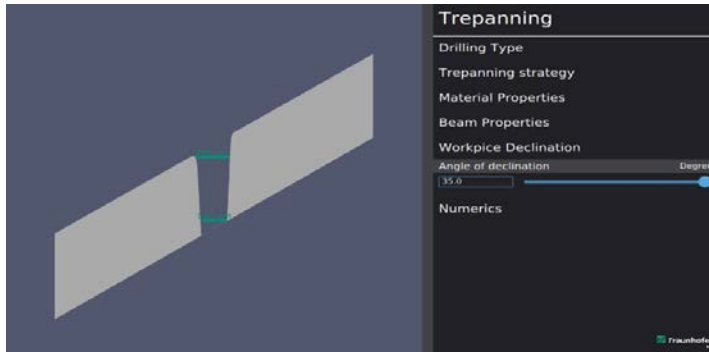


“Process design”

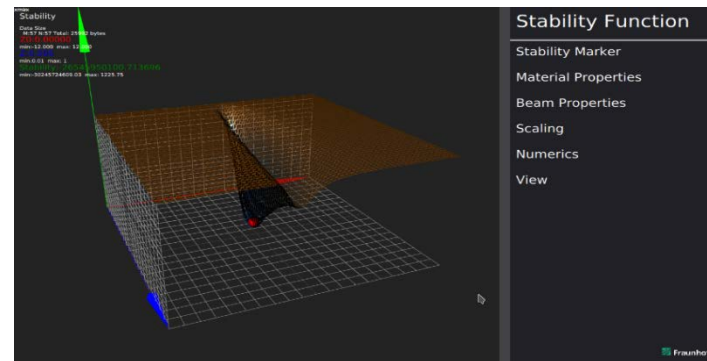




- Digitalization



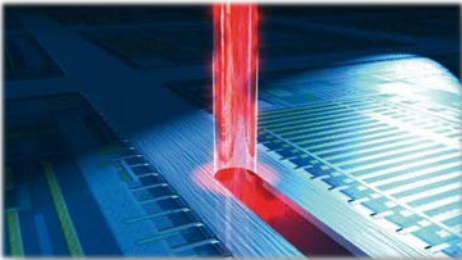
Customer simulation tools from department of Nonlinear dynamics of laser manufacturing processes in RWTH Aachen University





Outlook: getting more industrial decision making tools or knowledge from sparse and real data in knowledge intensive manufacturing processes.

Cutting



Welding



Drilling



Additive Manufacturing



Patterning



Customer Simulation Tools





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Challenges for a data-driven society

- Thank you for your attention
- Business and commercial corporation:
- Please contact:
- You Wang
- you.wang@ilt.fraunhofer.de