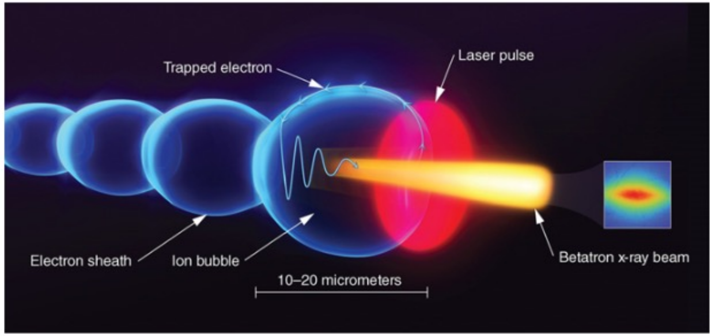
HELMHOLTZ AI | ARTIFICIAL INTELLIGENCE COOPERATION UNIT

Data-Driven Shadowgraph Simulation of a 3D Object

Anna Willmann
Hoffmann Group
Helmholtz-Zentrum Dresden-Rossendorf

Motivation: Physical Model
Laser Wakefield Acceleration

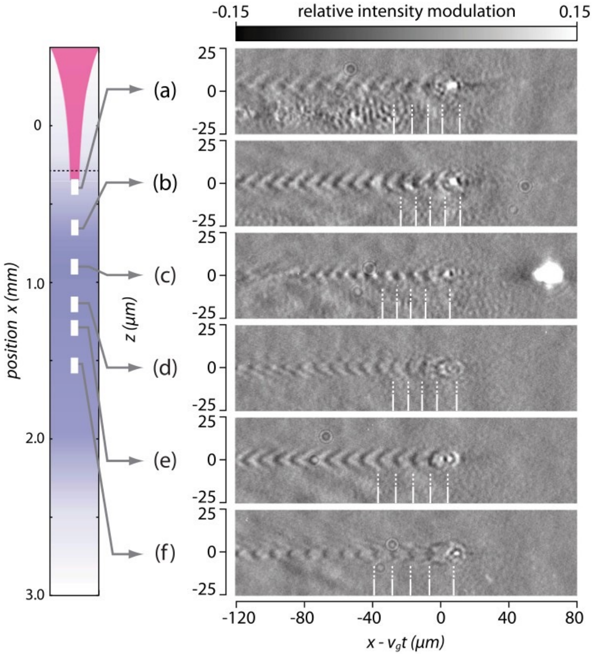
- A high intensity laser pulse propagates through plasma and generates a plasma electron density wave behind it
- The resulting plasma wave is called "laser wakefield" supports high electric fields, and electrons can be accelerated to high energies in these fields within a very short length



Felicie Albert, Alec Thomas, Stuart Mangles, S Banerjee, S´ebastien Corde, A. Flacco, Michael Litos, D Neely, J. Vieira, Zulfikar Naj-mudin, Robert Bingham, Chandrashekhar Joshi, and T Katsouleas.Laser wakefield accelerator based light sources: Potential applications and requirements. Plasma Physics and Controlled Fusion,56:084015, 07 2014

Motivation: Physical Model
Shadowgraph

- Shadowgraph is a technique to visualize LWFA process
- Associated with the electron density distribution within the plasma wave
- Provide information about its size and shape



A. Saevert, S. P. D. Mangles, M. Schnell, E. Siminos, J. M. Cole, M. Leier, M. Reuter, M. B. Schwab, M. Moeller, K. Poder, O. Jaeckel,G. G. Paulus, C. Spielmann, S. Skupin, Z. Najmudin, and M. C.Kaluza. Direct observation of the injection dynamics of a laser wake-field accelerator using few-femtosecond shadowgraphy.Phys. Rev.Lett., 115:055002, Jul 2015

Motivation: Physical Model

Shadowgraph

Simulation of plasma cavities

Motivation: Physical Model

Shadowgraph

Propagating EM field through the object

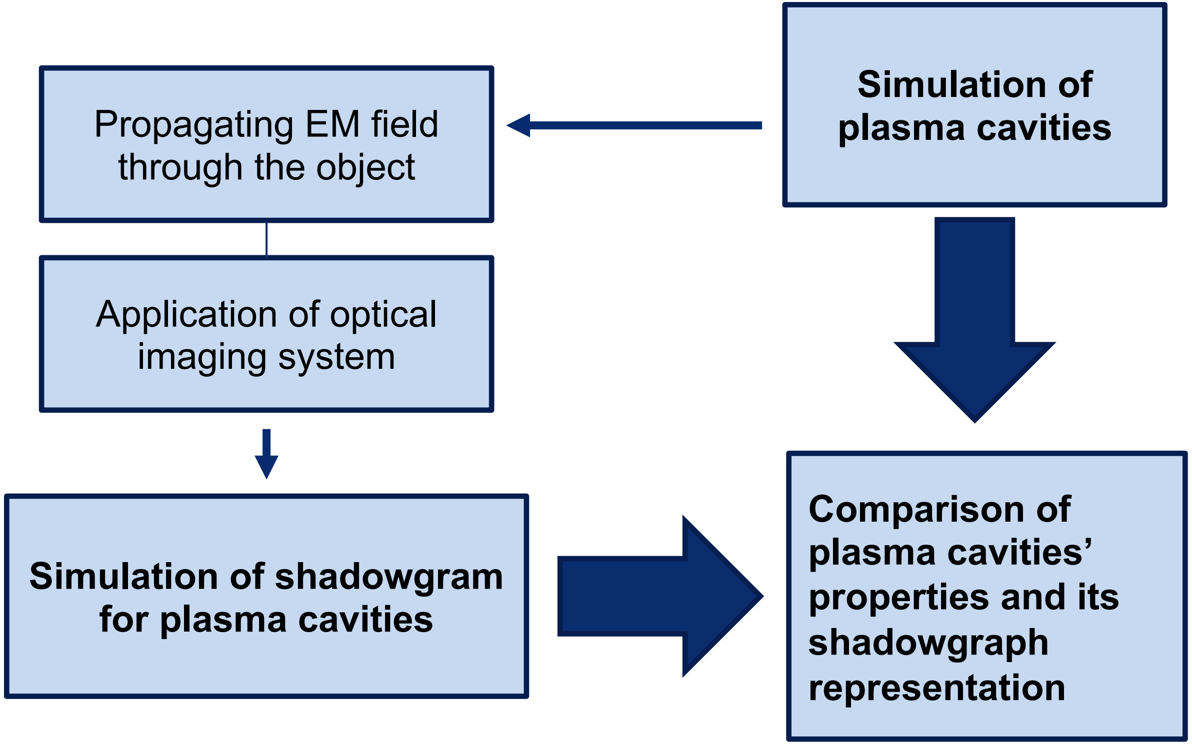
Simulation of plasma cavities

Application of optical imaging system

Simulation of shadowgram for plasma cavities

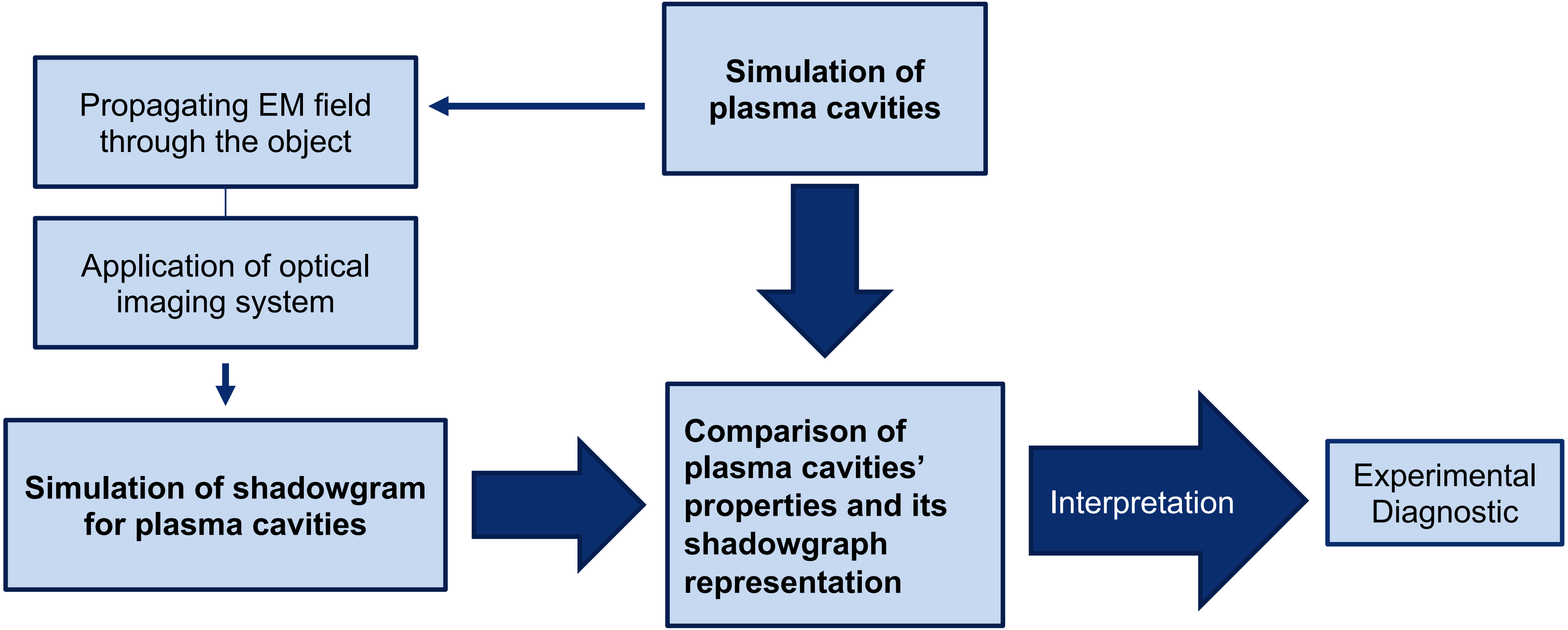
Motivation: Physical Model

Shadowgraph



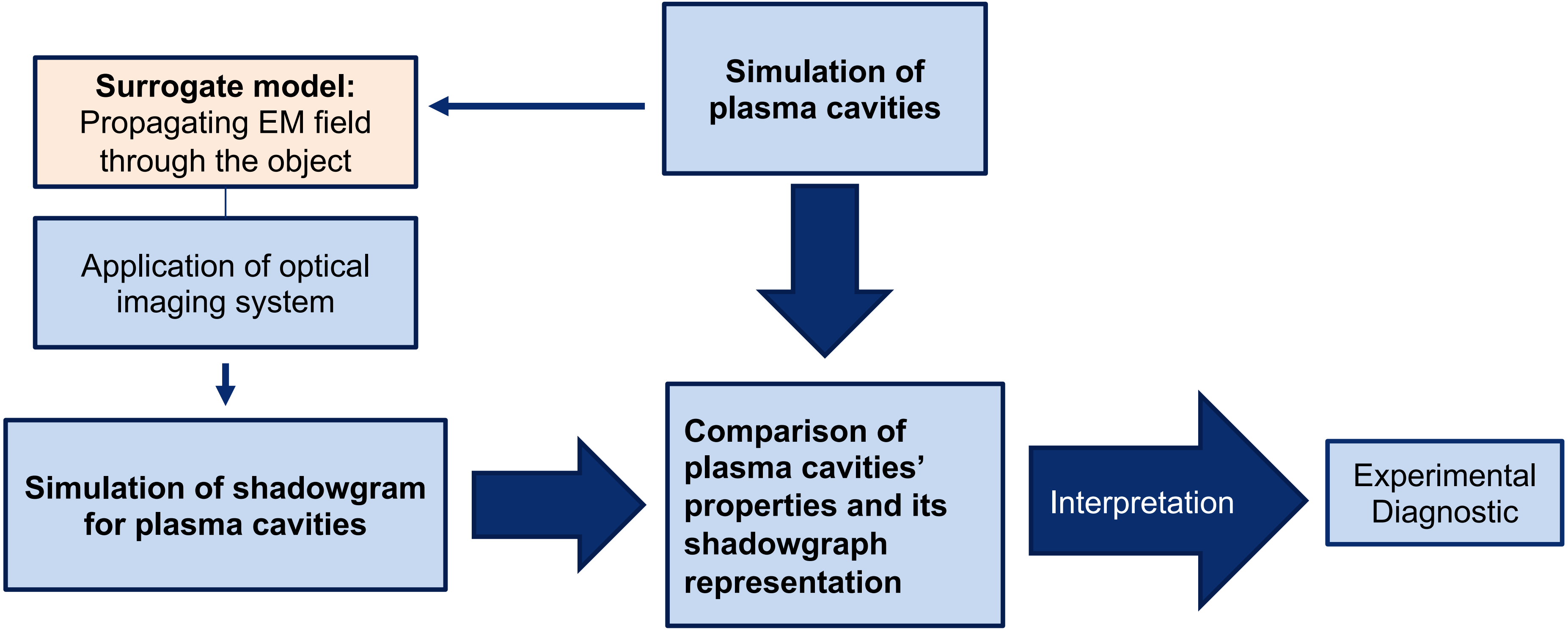
Motivation: Physical Model

Shadowgraph



Motivation: Physical Model

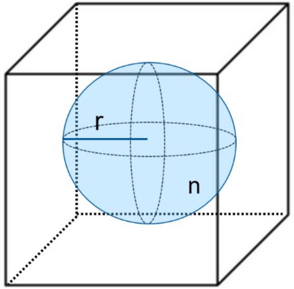
Shadowgraph



Target simulation
Shadowgram of a simple object

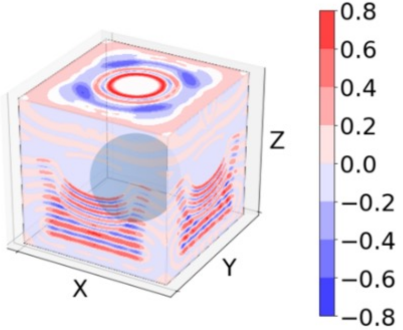
- Evaluation of the first surrogate model on simulations of a shadowgraph for a simple object
- Solution is approximated by finite difference time domain method, implemented in library Meep[1].

Sphere in a 3D cell



r – radius
n – refractive index of material

Field propagation



size of cell = 12μm × 12μm × 12μm
boundary: absorbing layer of 2μm

[1]: Ardavan F. Oskooi, David Roundy, Mihai Ibanescu, Peter Bermel,J.D. Joannopoulos, and Steven G. Johnson. Meep: A flexible free-software package for electromagnetic simulations by the fdtd method. Computer Physics Communications, 181(3):687 – 702, 2010

Shadowgraph Surrogate Model
Problem statement

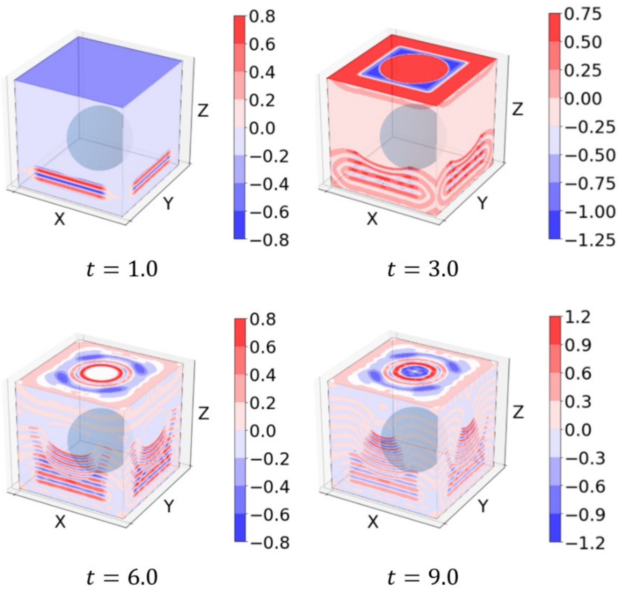
<u>Physical model:</u> propagation of 3D electrical field given by Maxwell's equations through a cell with a sphere with varying radius and refractive index

<u>Aim:</u> interpolated field propagation based radius and refractive index of the sphere

<u>Idea:</u>

Reduced Order Model

1. Compression of 3D field data by autoencoder into a reduced space
2. MLP-based mapping from parameter space to the reduced space (based on pre-trained AE)



Shadowgraph Surrogate Model

Compression method

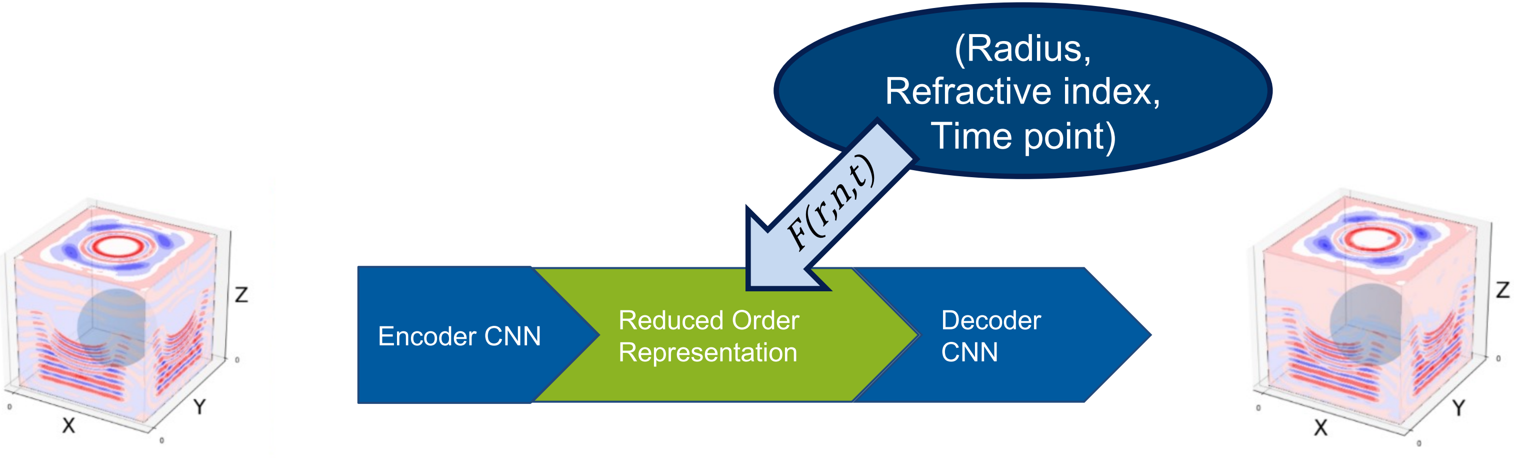
- A convolutional autoencoder to decrease dimensionality of space and reconstruct it back to the original size for reduction of memory consumption and time of fast-forward computations

- Objective function is a supervised reconstruction error

Shadowgraph Surrogate Model

Simulation in the reduced space

- MLP-based mapping F between simulation parameters and its dimensionaly reduced representation
- Objective function is a supervised approximation error



Shadowgraph Surrogate Model

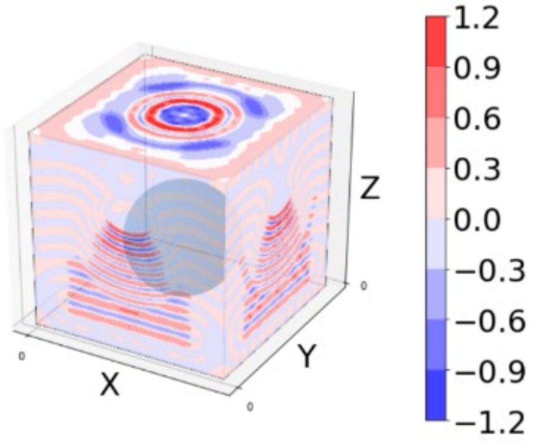
Simulation in the reduced space

Surrogate model scheme:

1. Map given parameters to a reduced respresentation of the field propagation
2. Decompression to the original dimensionality

Shadowgraph Surrogate Model

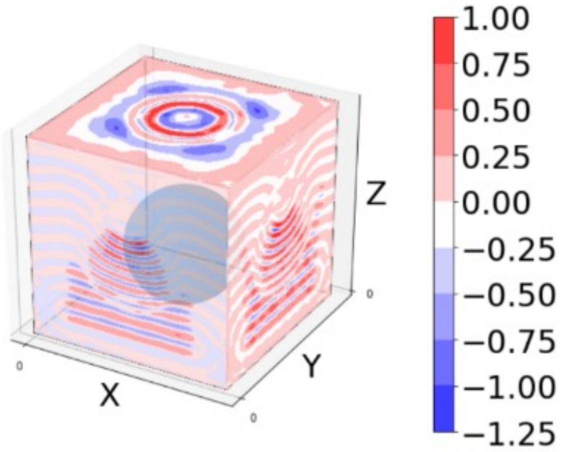
Results



$r = 3.25\mu m, n = 1.65, t = 9.0$

Question

Which volume is ground-truth?



$r = 3.25\mu m, n = 1.65, t = 9.0$

Shadowgraph Surrogate Model

Results

Autoencoder

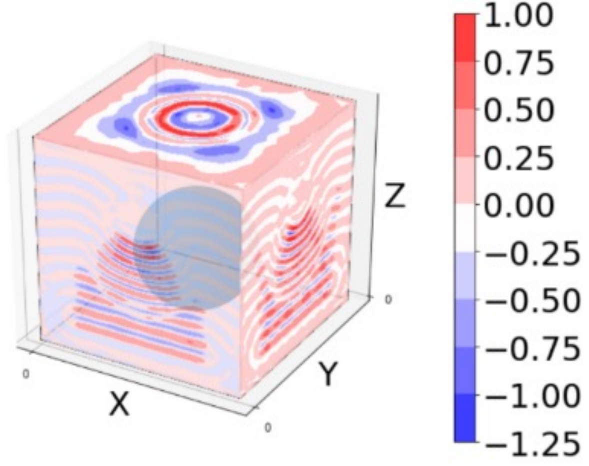
- Size of training data: 18Gb per simulation,
  35 simulations in total
- Training time of the autoencoder: 29 hours
- Resources: 28 GPUs NVIDIA V100

→ Compression rate: 7020

Surrogate Model

- MLP-based projection from parameters to latent space
- Training time: 6 hours
- Resources: 8 GPUs NVIDIA V100

→ Average interpolation error: 0.01813



$r = 3.25\mu m, n = 1.65, t = 9.0$

Shadowgraph Surrogate Model
Summary

- Developed a surrogate model for field propagation in 3D
- Recurrency of computation in temporal dimension is avoided
- High compression rate of 3D field data
- Technical preparation is finished for a simple problem, and the model can be extended to simulations with more complex objects

Published as a workshop paper at ICLR 2021 SimDL Workshop

DATA-DRIVEN SHADOWGRAPH SIMULATION OF A 3D OBJECT

Anna Willmann[1], **Patrick Stiller**[1], **Alexander Debus**[1], **Arie Irman**[1], **Richard Pausch**[1], **Yen-Yu Chang**[1], **Michael Bussmann**[1,2], **Nico Hoffmann**[1]

[1] Helmholtz-Zentrum Dresden - Rossendorf, Bautzner Landstrasse 400, 01328 Dresden, Germany
[2] CASUS - Center for Advanced Systems Understanding, Untermarkt 20, 02826 Görlitz, Germany
a.willmann@hzdr.de

Thank you for your attention!