Fast optimization of additively manufactured metallic parts with a combination of adaptive feedforward control and numerical simulation (SMARTAM)

Academic Partners:

R. Logé (EPFL), C. Leinenbach & K. Wasmer (Empa), S. Van Petegem (PSI), J. F. Löffler (ETHZ)

Industrial Partners:

PX Group, Heraeus Materials, Patek Philippe, Swatch Group

Potential other industrial partners:
Richemont-Varinor, Rolex SA

Project overview - Motivation

Laser Powder Bed Fusion (LPBF) is a layer by layer deposition additive manufacturing technique

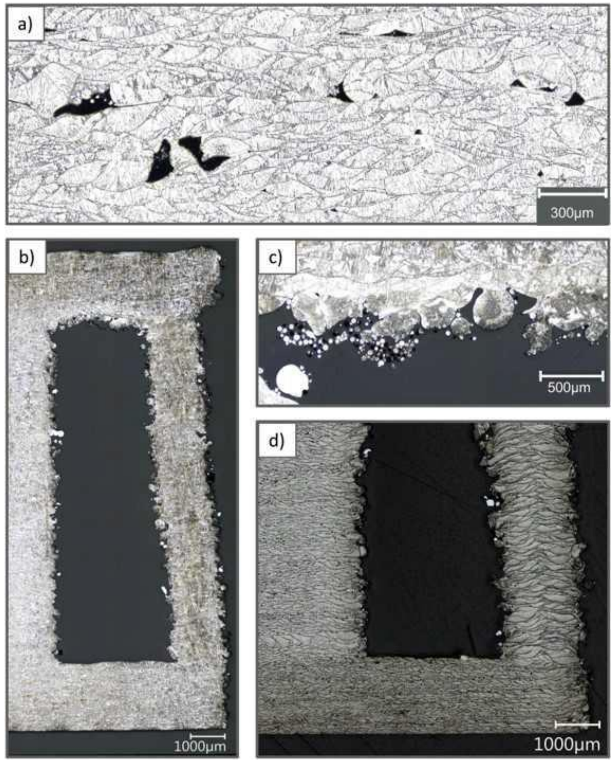
Single sets of process parameters are defined for a given part despite its intricate geometry.

Dependency of heat flux on geometrical features results in variations in melt pool geometry which may lead to the formation of undesirable defects.

Variations in the imposed local thermal history additionally can result in undesirable microstructure.

REMEDY

Part specific and **location specific** process parameters can be derived from numerical simulations and machine learning algorithms.



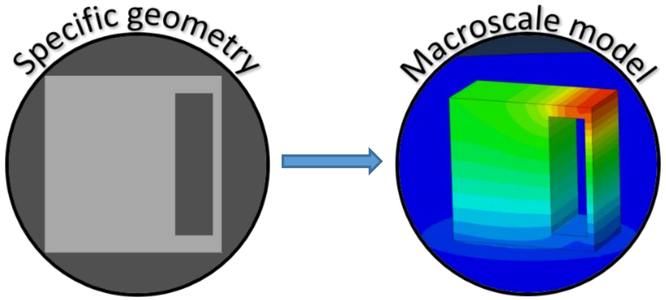
C.L. Druzgalski, et al. Additive Manufacturing, (2020)

Project work flow

Core workflow

Verification/improvement

Training – A priori



Macro-scale model

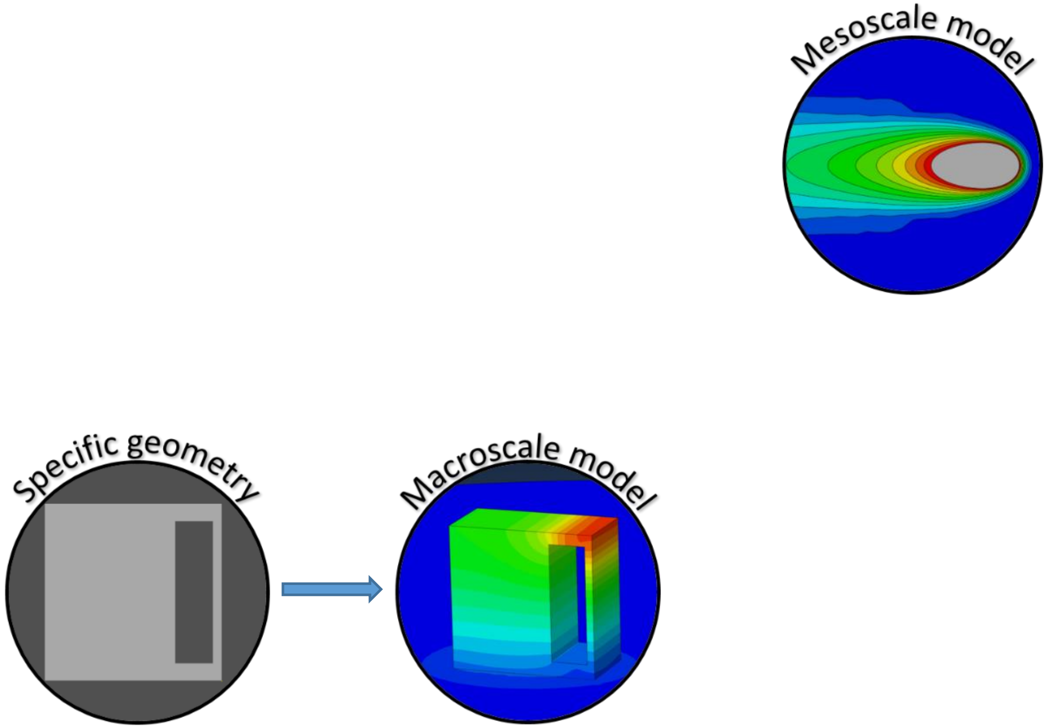
Credits: Lucas Schlenger, Toni Ivas, Milad Hamidi

Project work flow

Core workflow

Verification/improvement

Training – A priori



Meso-scale model

Credits: Lucas Schlenger, Toni Ivas

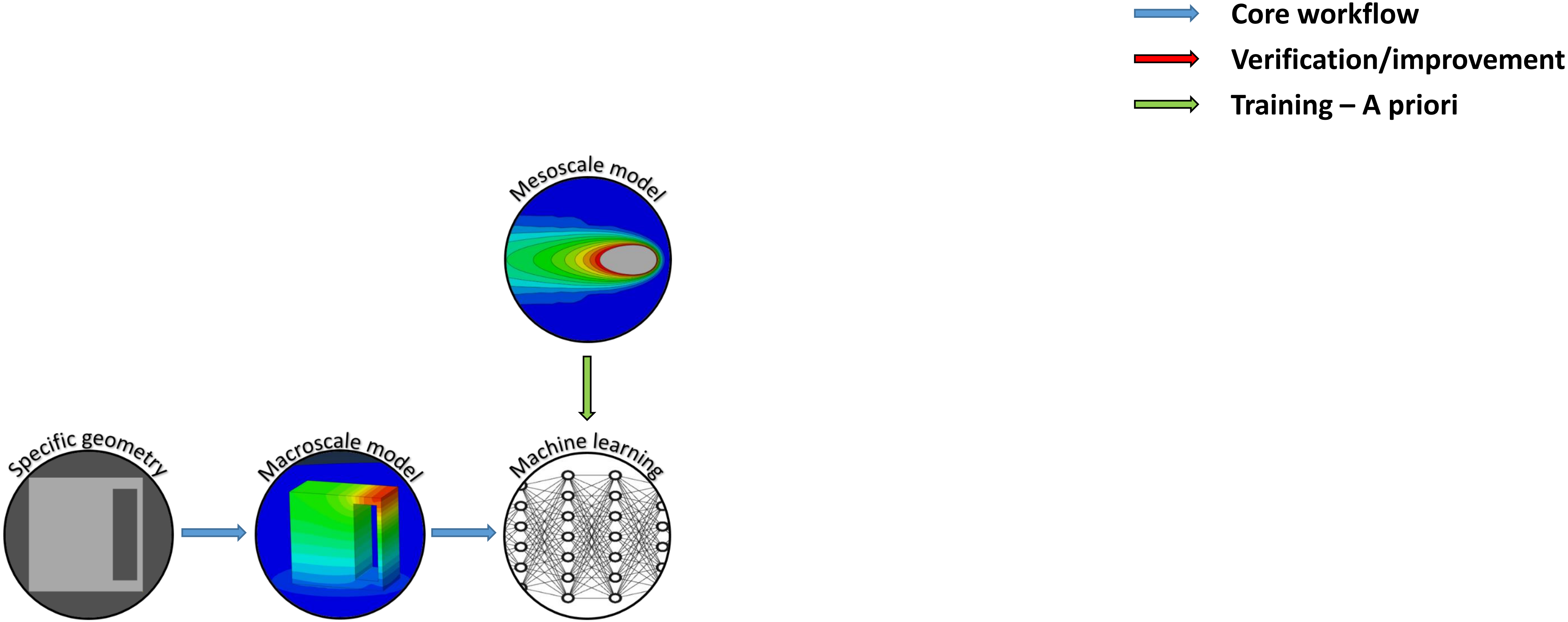
EPFL

Simulation in **melt pool scale** to obtain melt pool geometry

Design of Experiment (DOE):

- T_0; initial temperature
- P; Laser power
- *v*; Scanning velocity

Project work flow

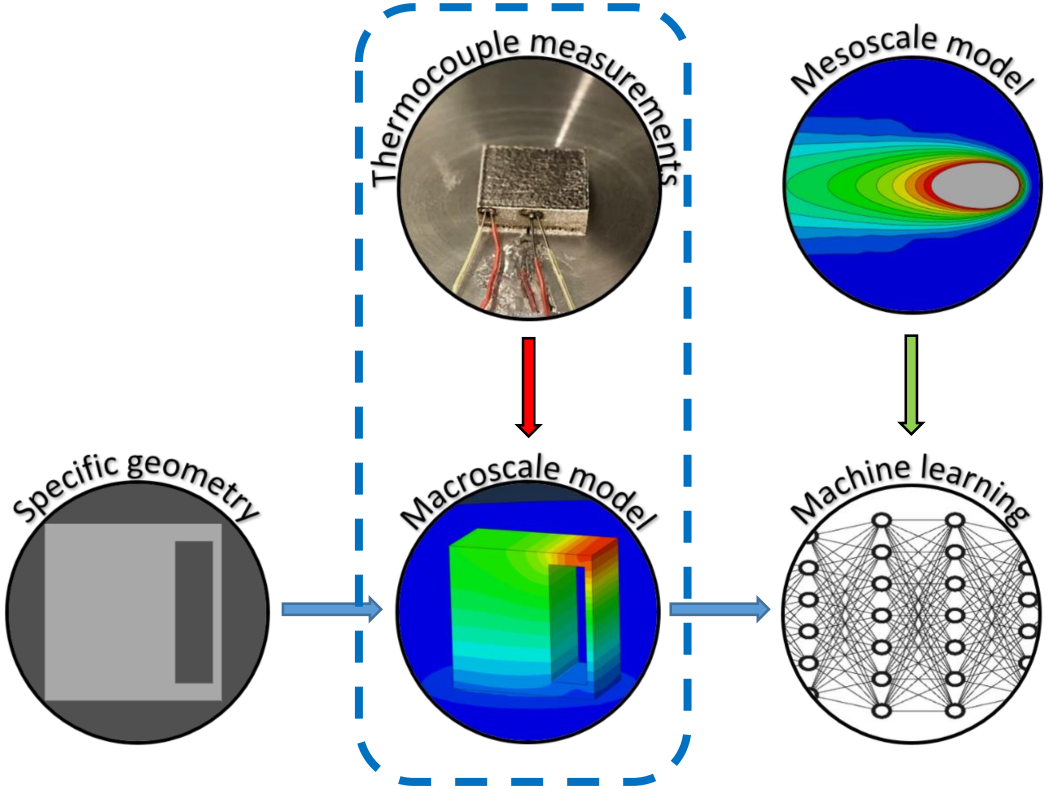


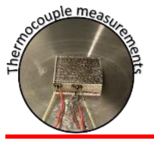
Project work flow

Core workflow

Verification/improvement

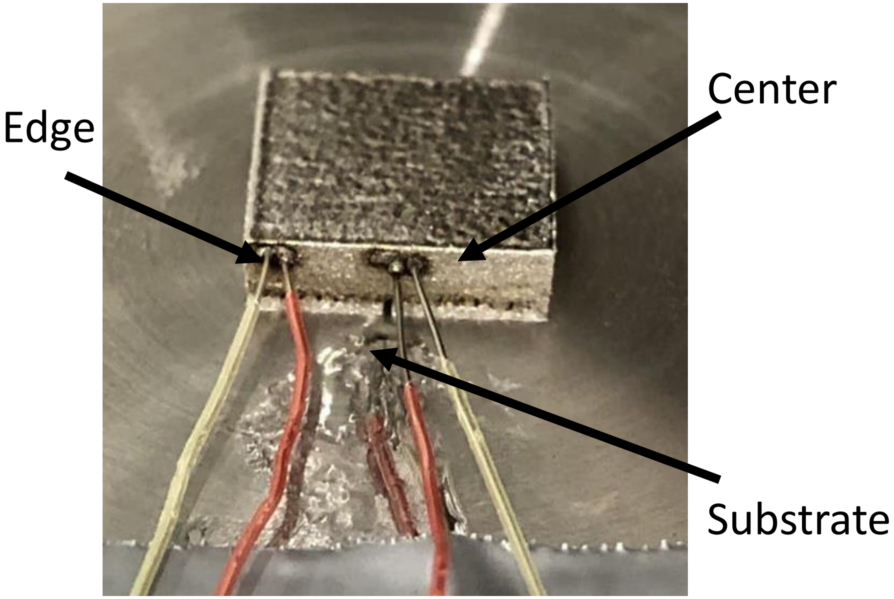
Training – A priori

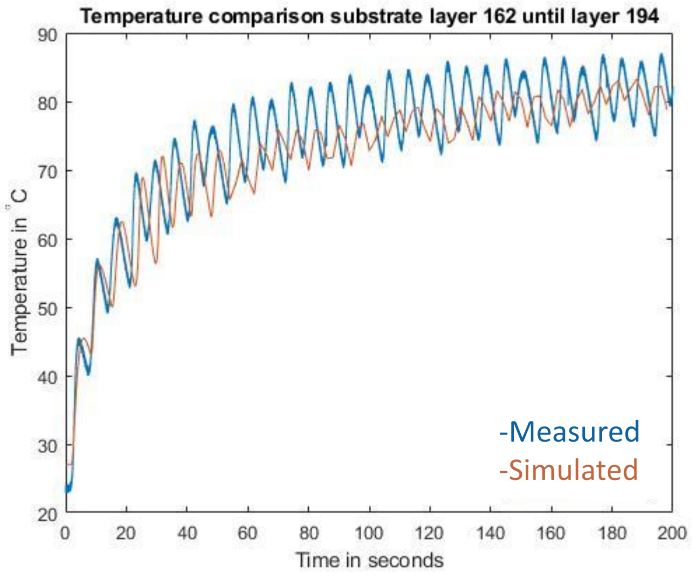


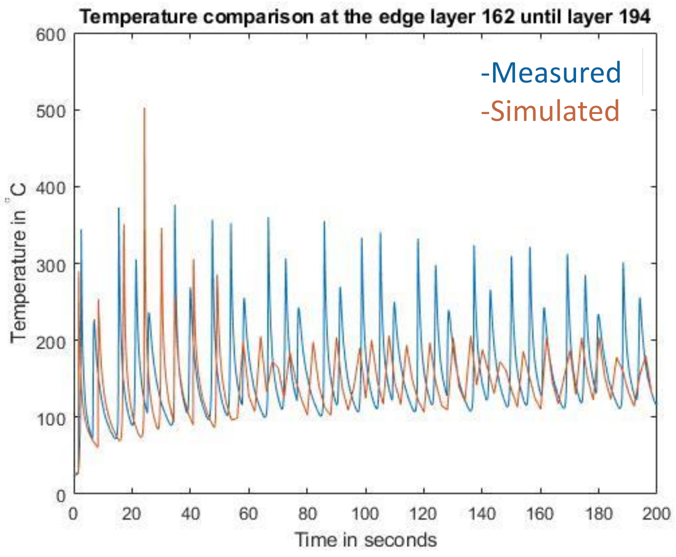


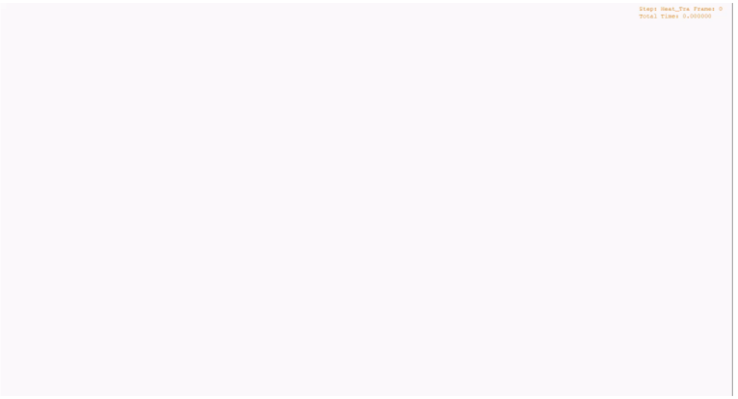
Macro-scale simulation - Calibration

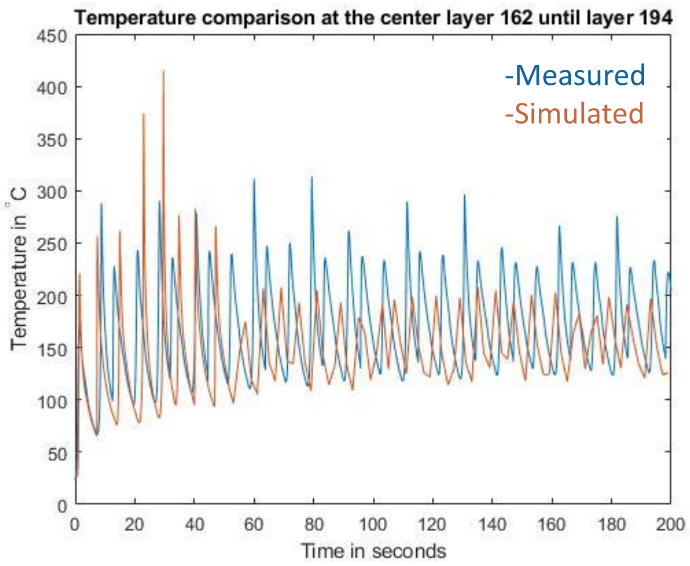
Credits: Lucas Schlenger, Jamasp Jhabvala

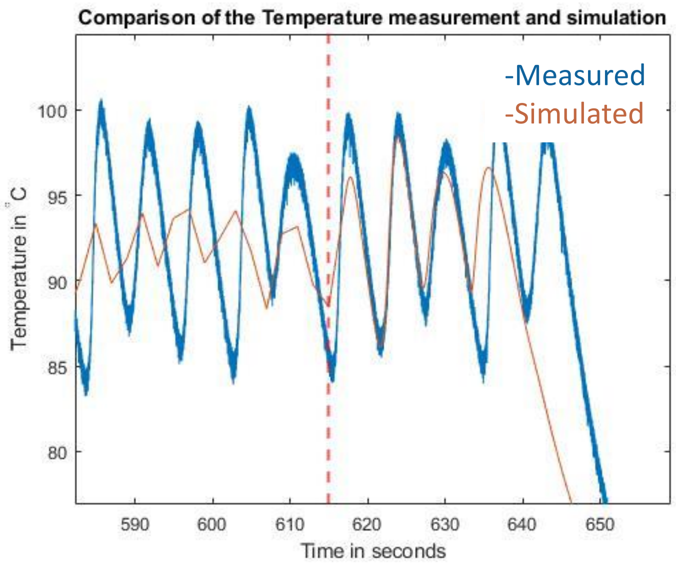






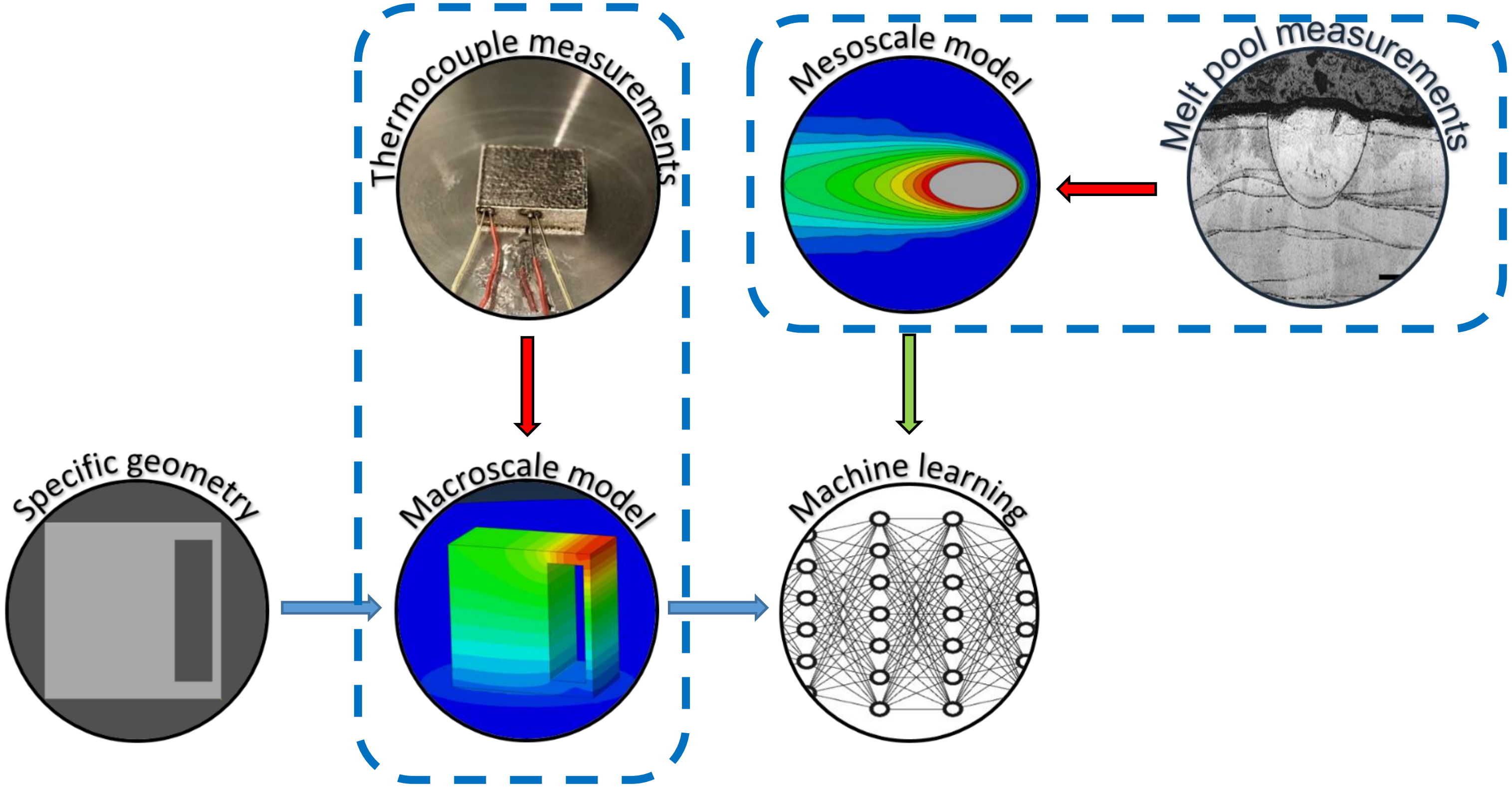




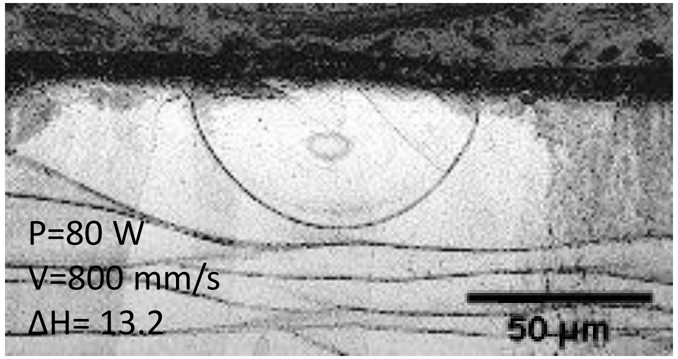


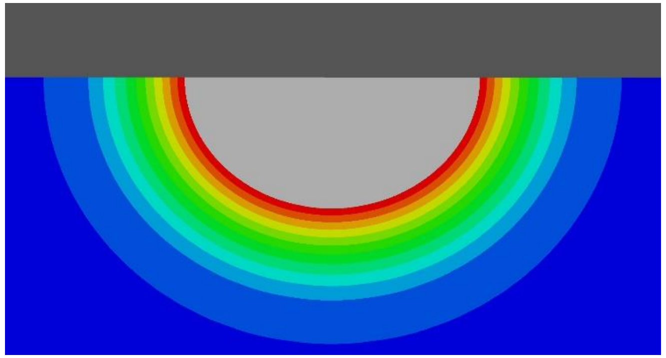
Project work flow

Core workflow
Verification/improvement
Training – A priori

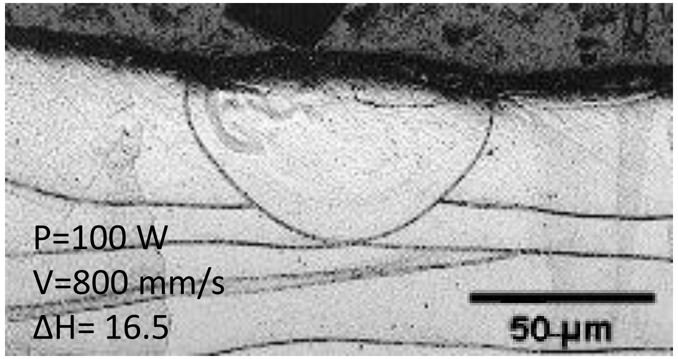


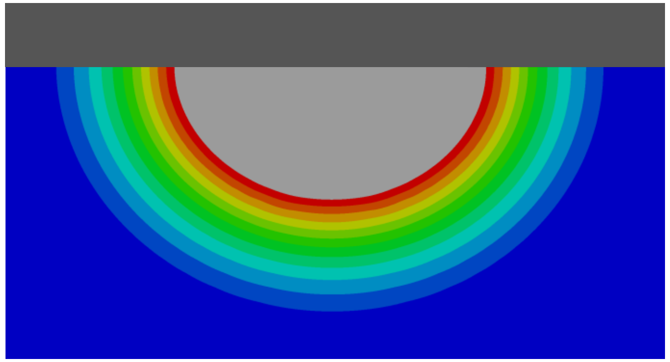
Meso-scale simulation - Calibration





	Width (µm)	Depth (µm)
Measured	69.1	36.3
Simulated	71.6	33.9



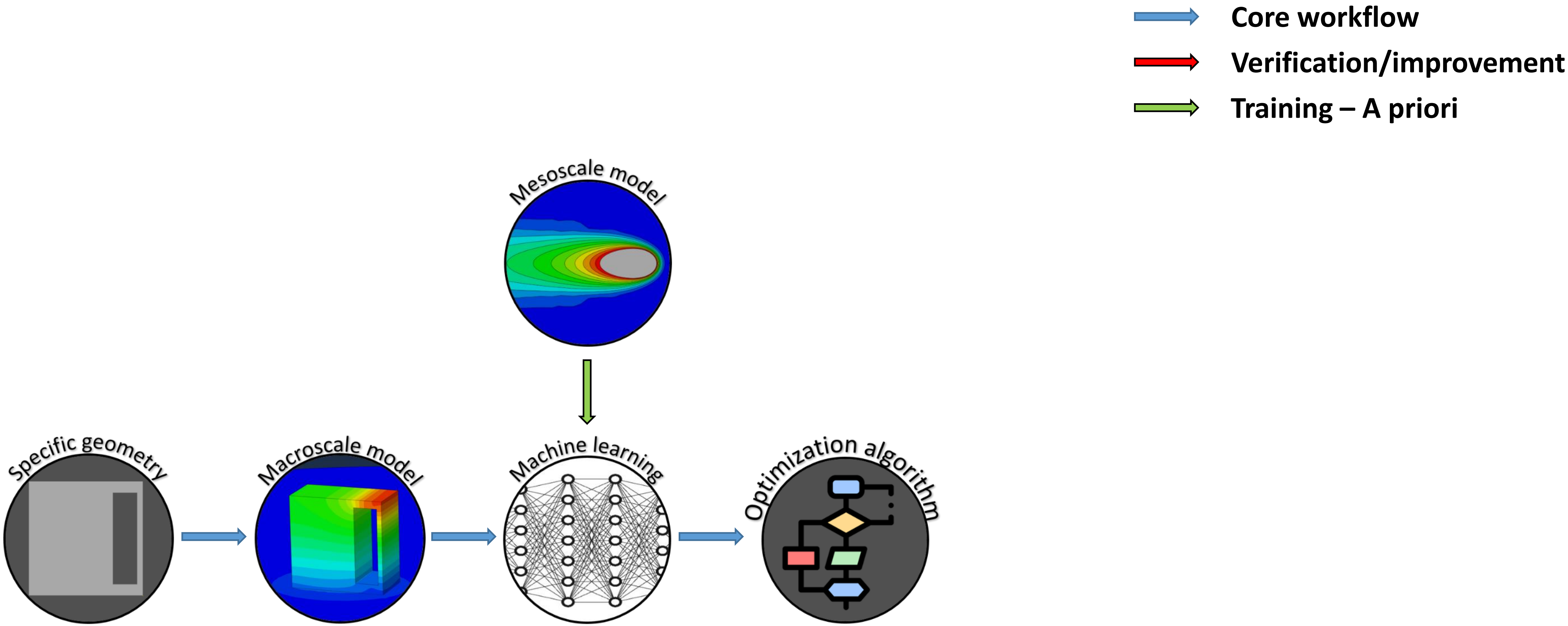


	Width (µm)	Depth (µm)
Measured	79.3	46.5
Simulated	80.4	37.1

Comparison study for 10 different samples

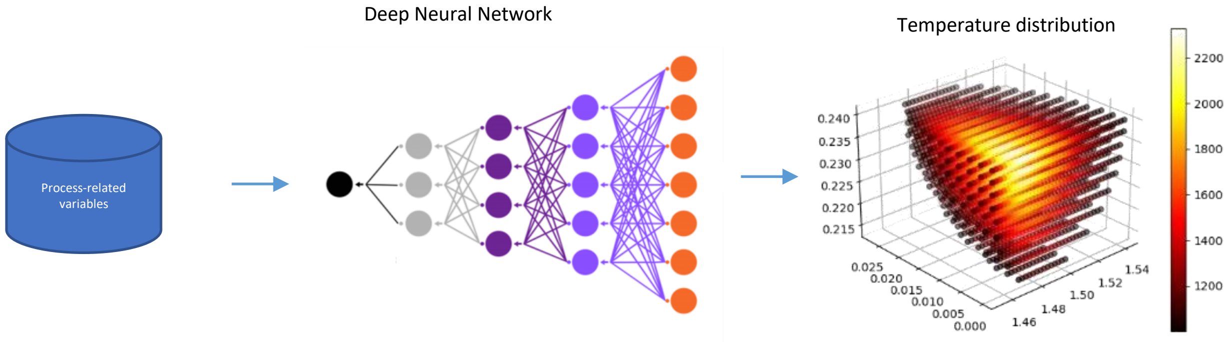
	Width (µm)	Depth (µm)
MAD	3.8	7.8
Bias	-0.02	-6.5

Project work flow

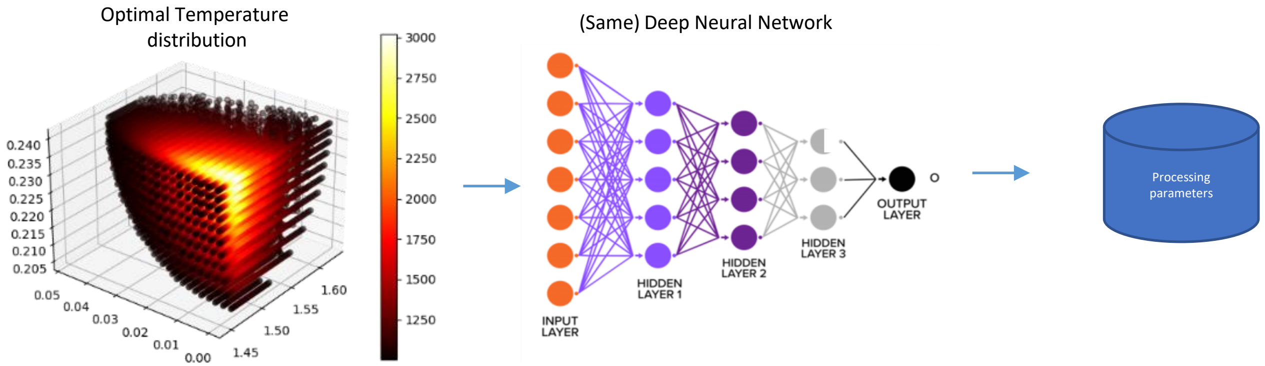


The trained Deep Neural network can solve two problems

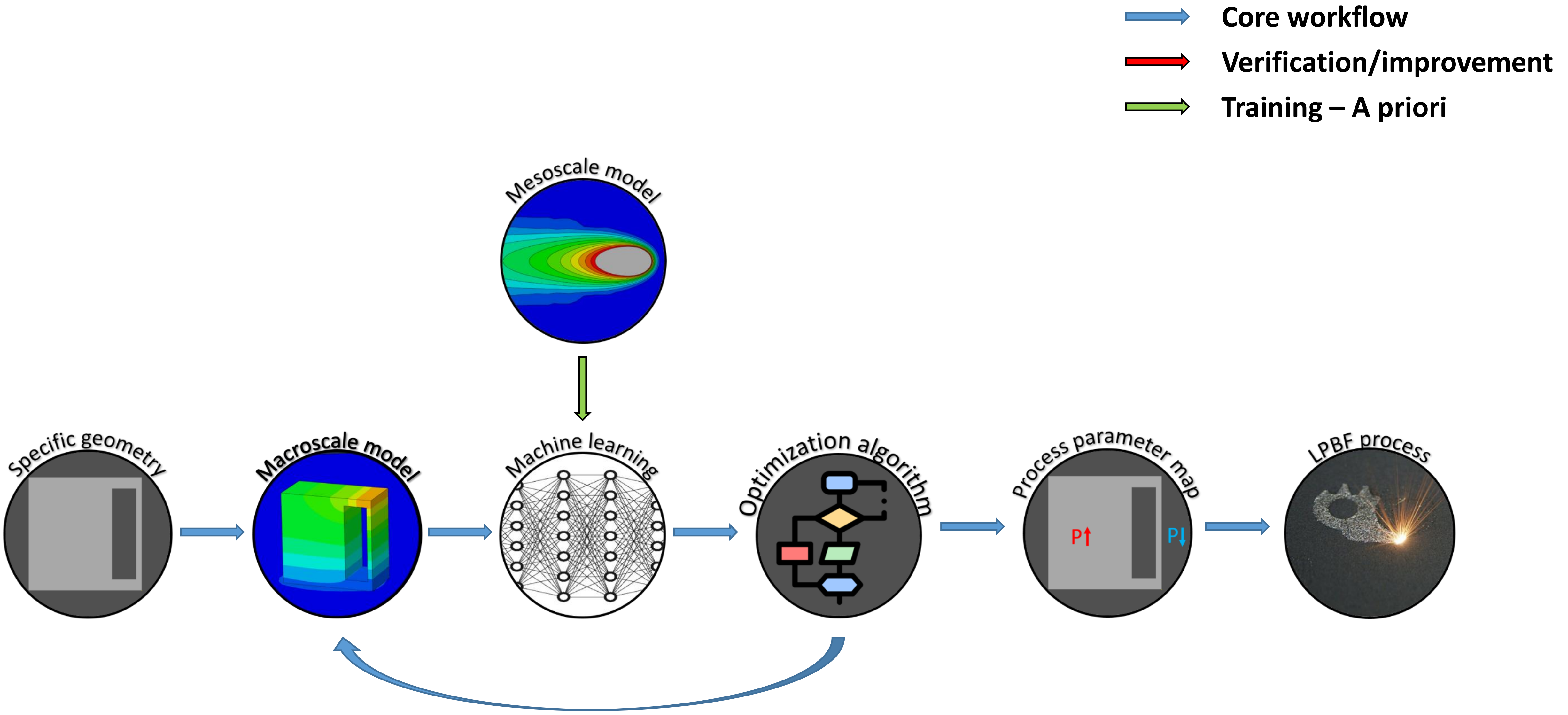
1. The Forward problem — replacing the steady state model:



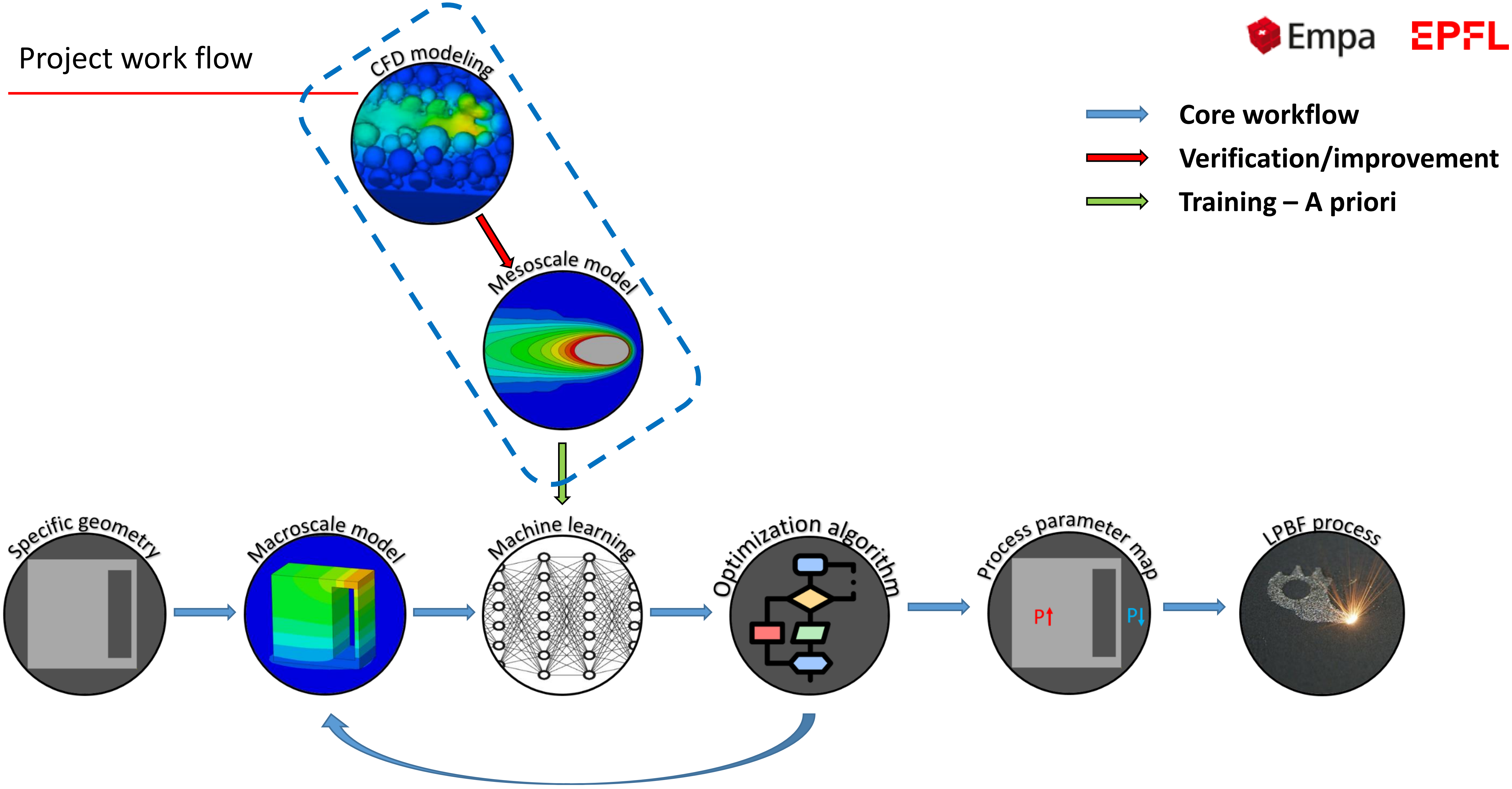
2. The Inverse problem — performing the desired optimization:



Project work flow



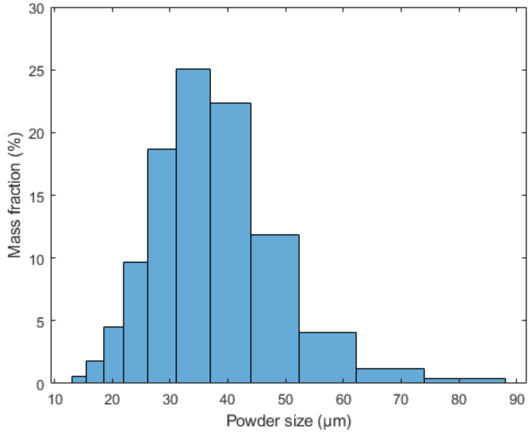
Project work flow

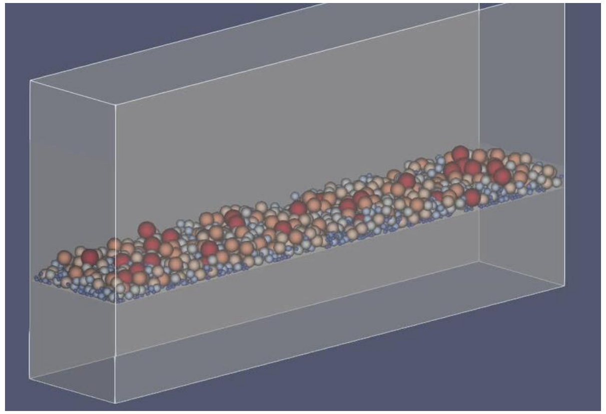


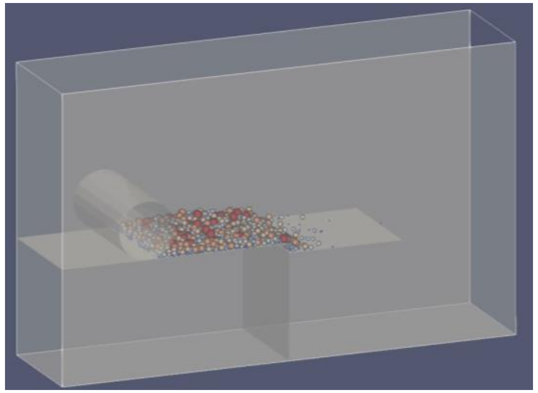
Computational Fluid Dynamics (CFD) Modeling

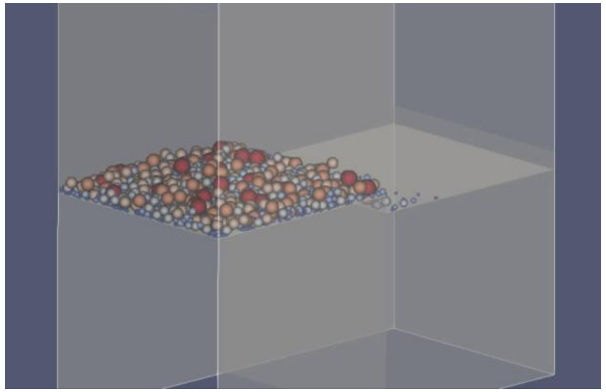
Credits: Jian Yang, Christian Leinenbach

Powder size distribution

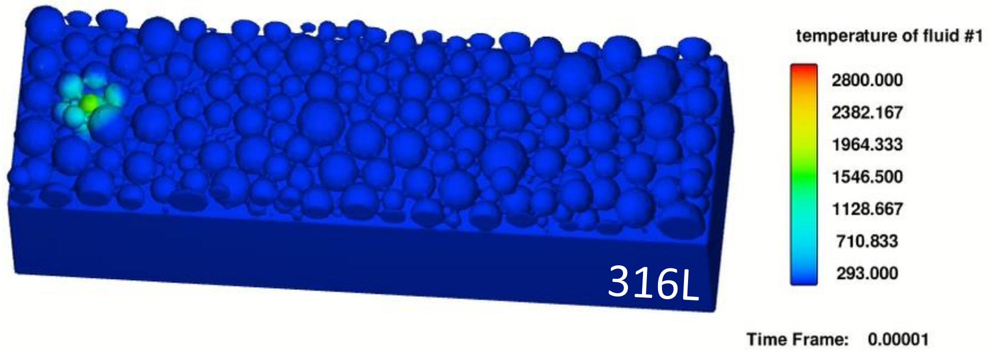


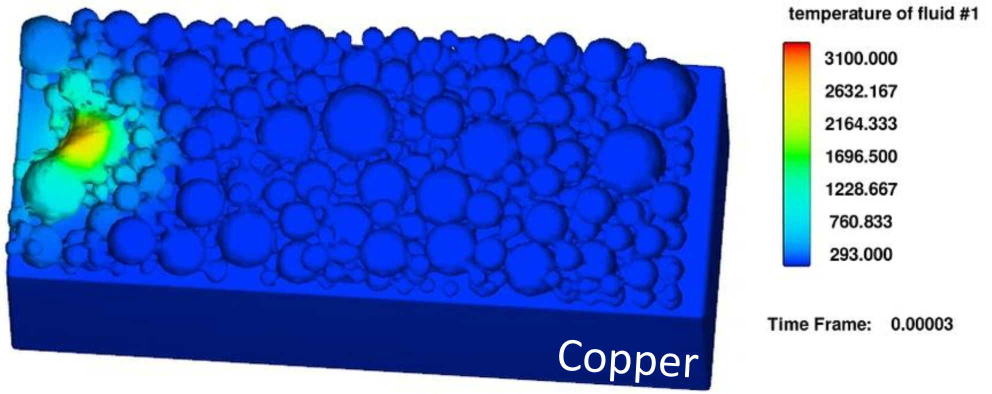






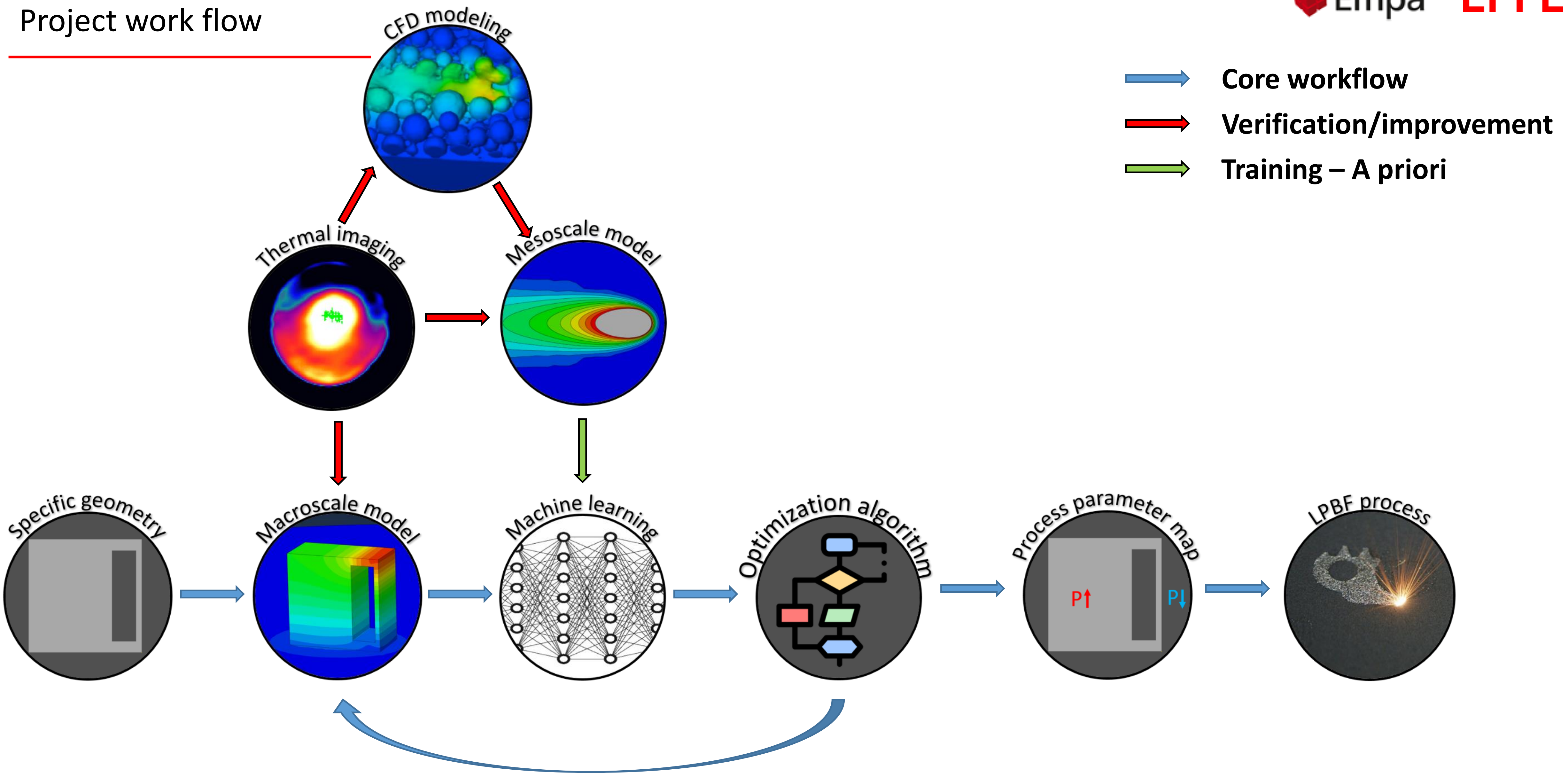
Different re-coating simulations (DED)





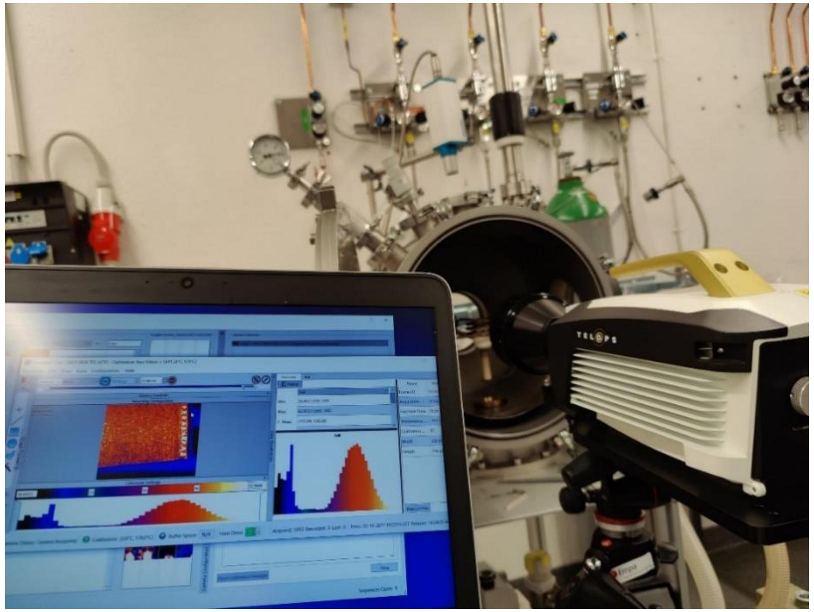
CFD simulations

Project work flow



Credits: Jian Yang, Lucas Schlenger, Jamasp Jhabvala, Christian Leinenbach

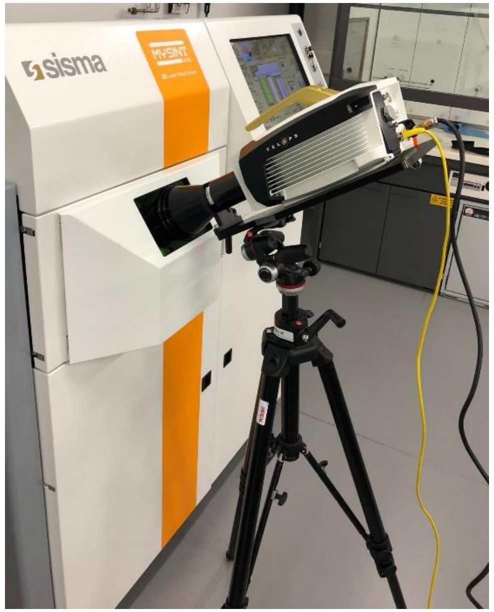
Empa EPFL

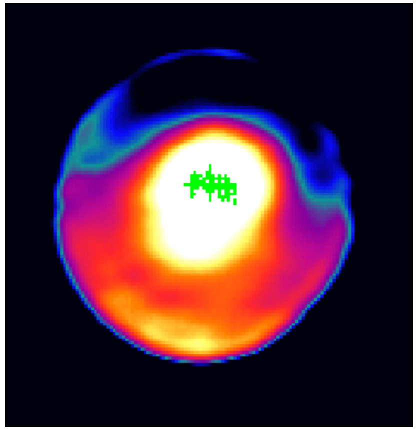


Calibration of emissivity ε with induction furnace and pyrometer

Close collaboration between EPFL and Empa

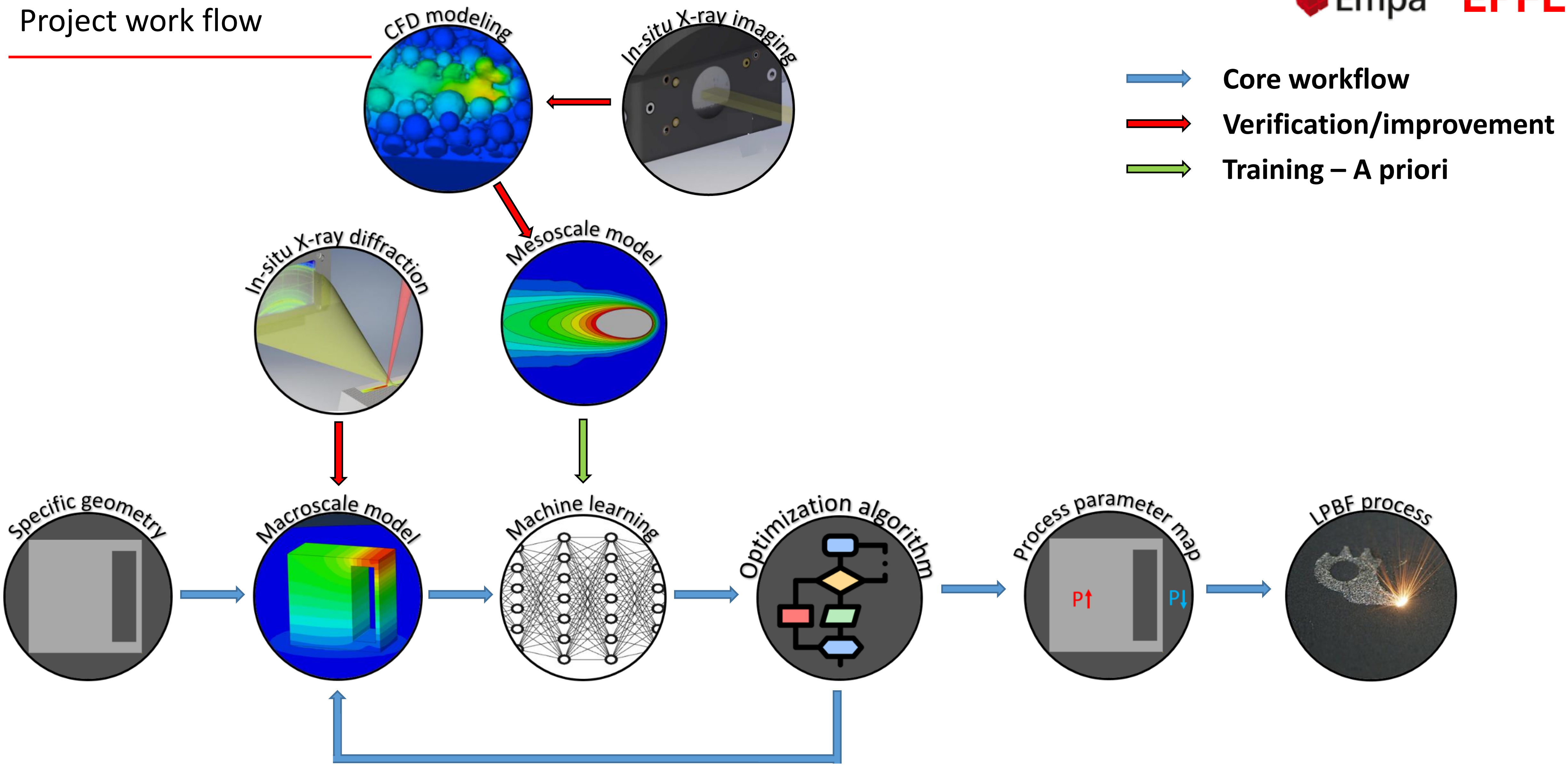
Experimental setup

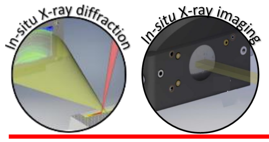




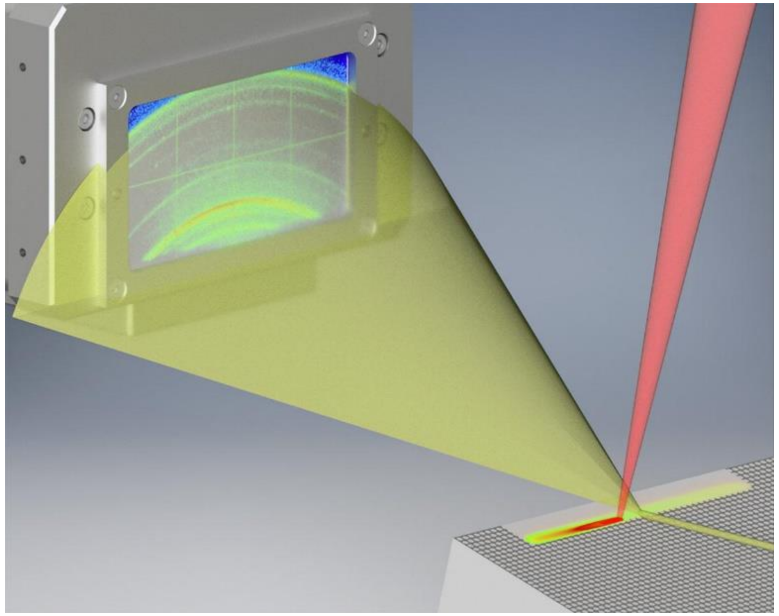
Melt pool measured on experimental LPBF machine

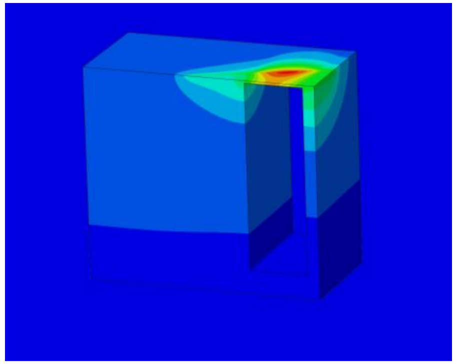
Project work flow

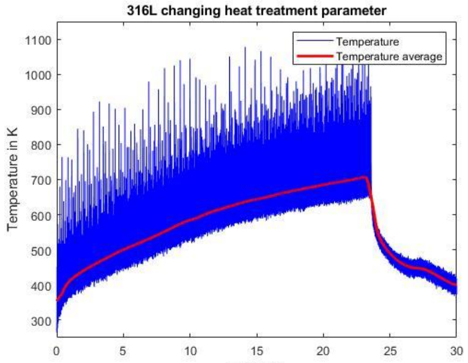




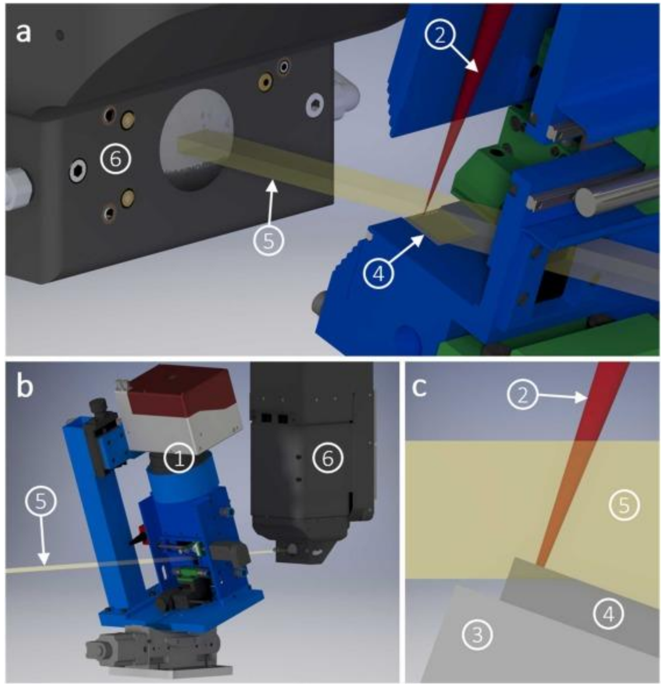
SLS Beamtime proposals

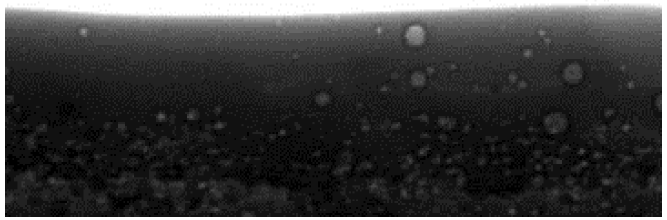






Operando X-ray diffraction

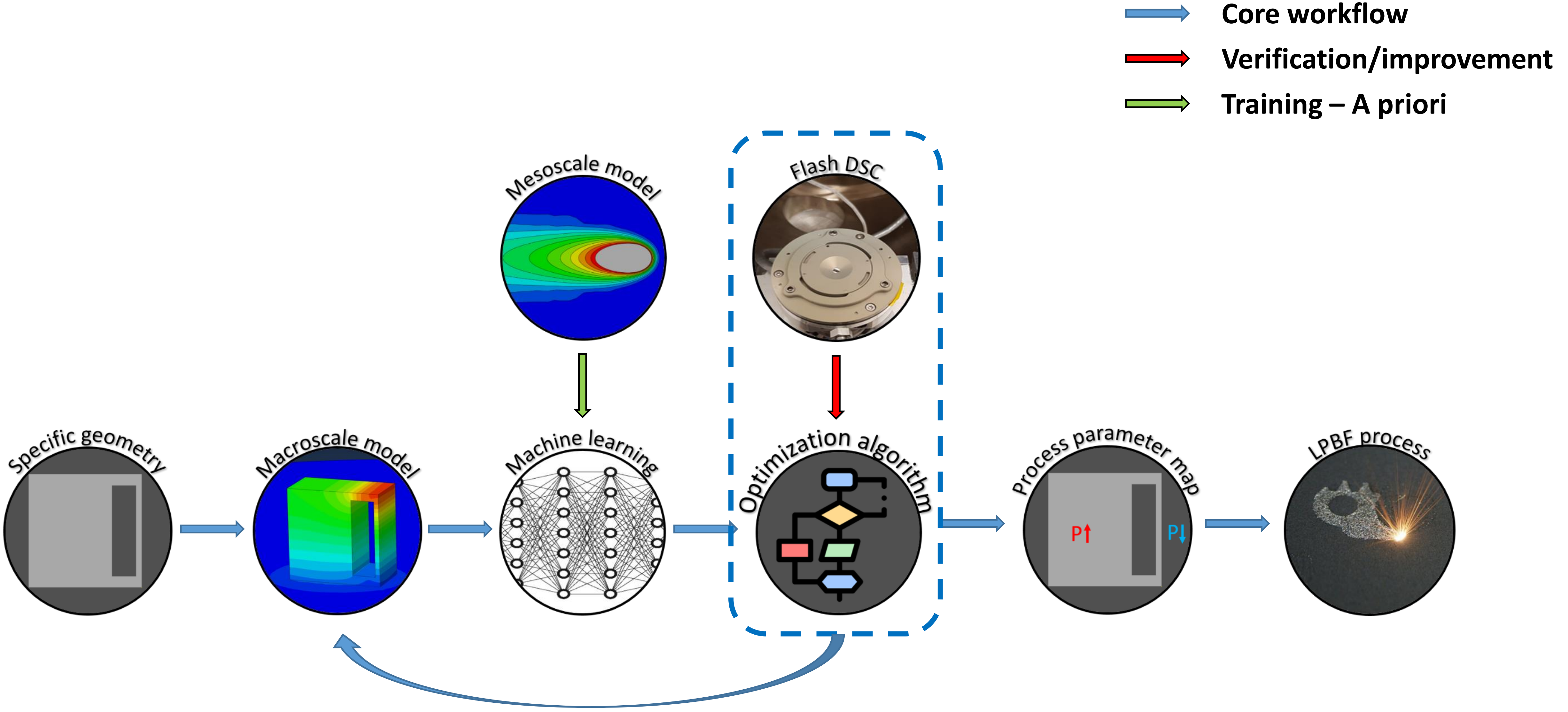




Operando X-ray imaging

Credits: Steven Van Petegem, Milad Hamidi, Lucas Schlenger, Jian Yang

Project work flow



In-situ FDSC

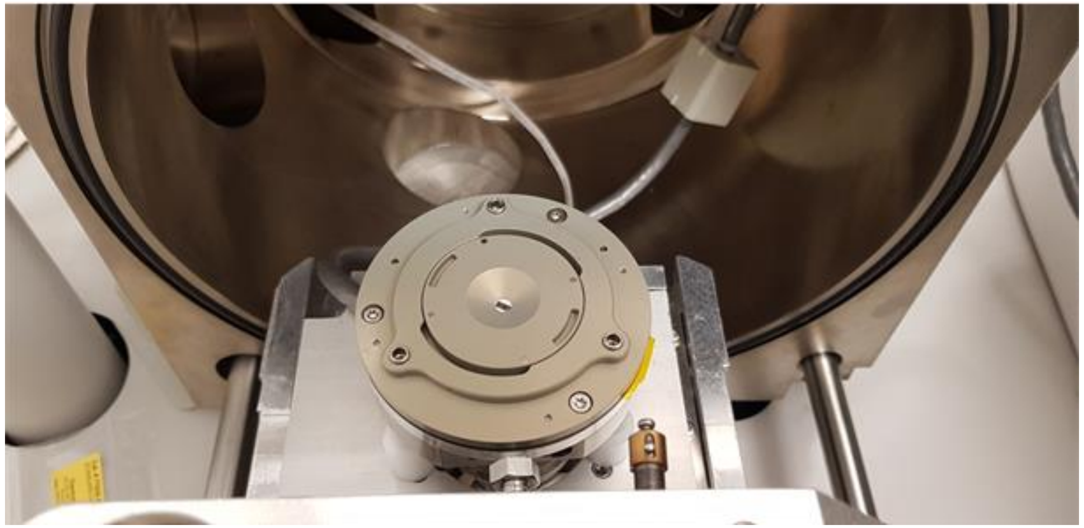
Credits: Štefan Stanko, Jörg F. Löffler

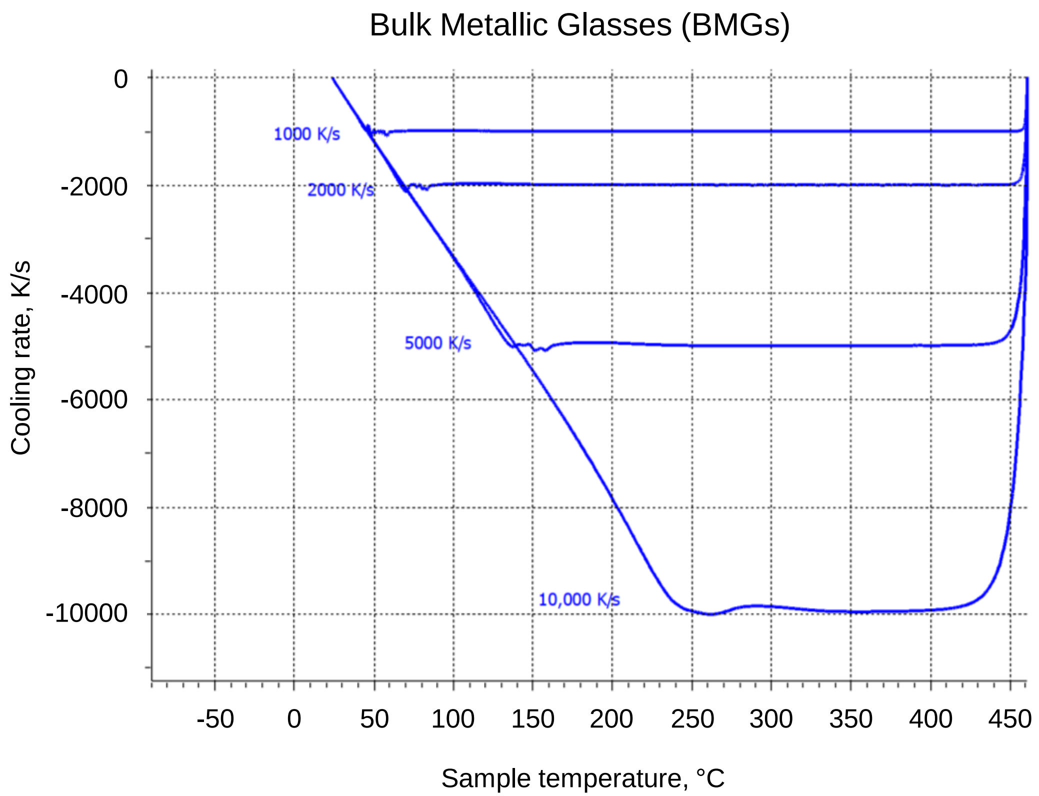
- calorimetry is sensitive, but not specific to structural changes

  → new *in situ* FDSC within a SEM

  (LMPT + ScopeM – ETH Zürich)

  - Thermo Fisher Scientific ESEM Quattro and Flash DSC 1 with UFS1 sensors (Mettler-Toledo)
  - SE detector, high frame rate
  - BSE, EDX planned in future
  - Limiting factor – slow signal collection in SEM





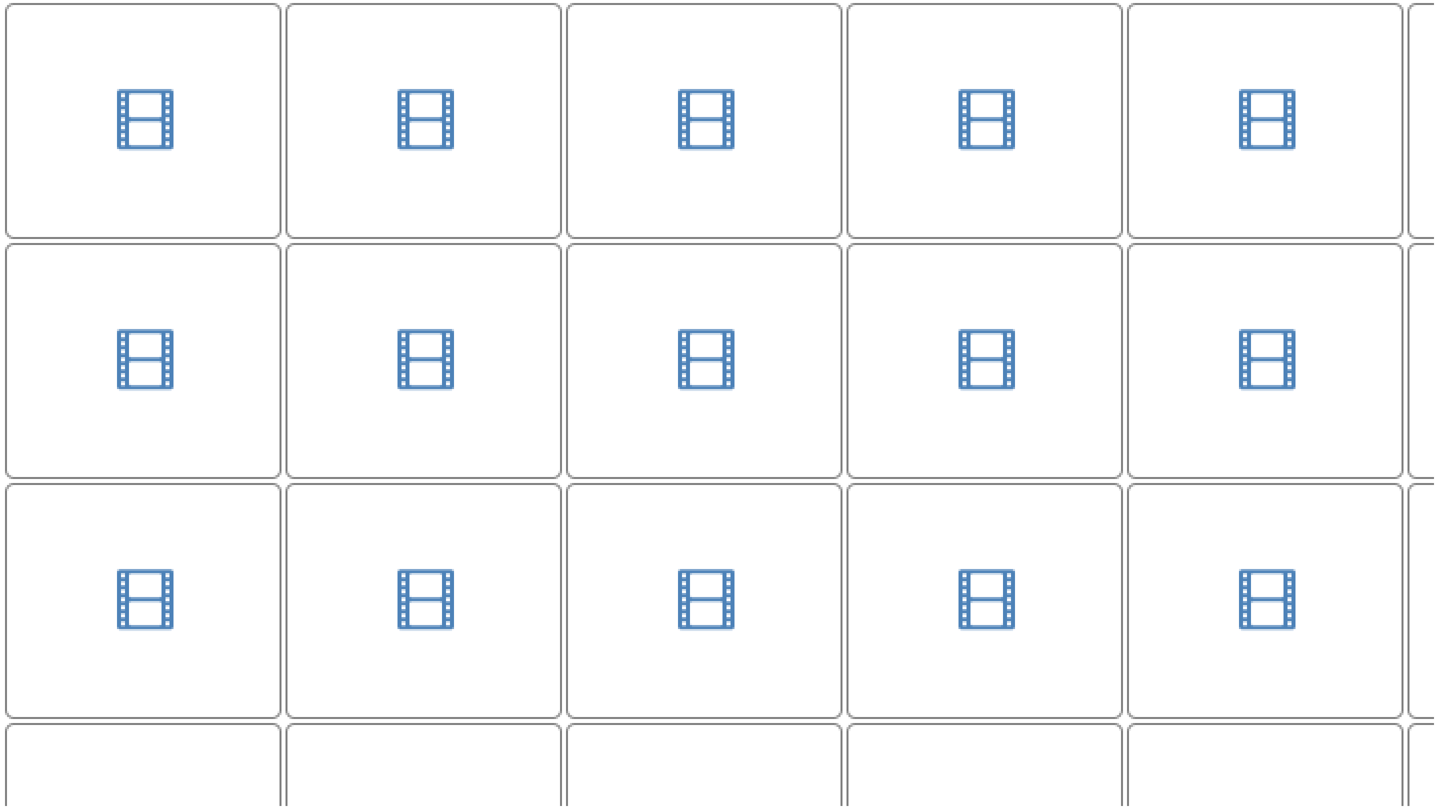
FDSC-SEM – cooling conditions

In-situ FDSC

Credits: Štefan Stanko, Jörg F. Löffler

- Structural changes AND simultaneous acquisition of heat flow signal
- Heating curves at 5 K/s after cooling from melt at various cooling rates were recorded
- Microstructural changes not seen in FDSC curves and thermal events observed without microstructure change

→ **complementary methods**



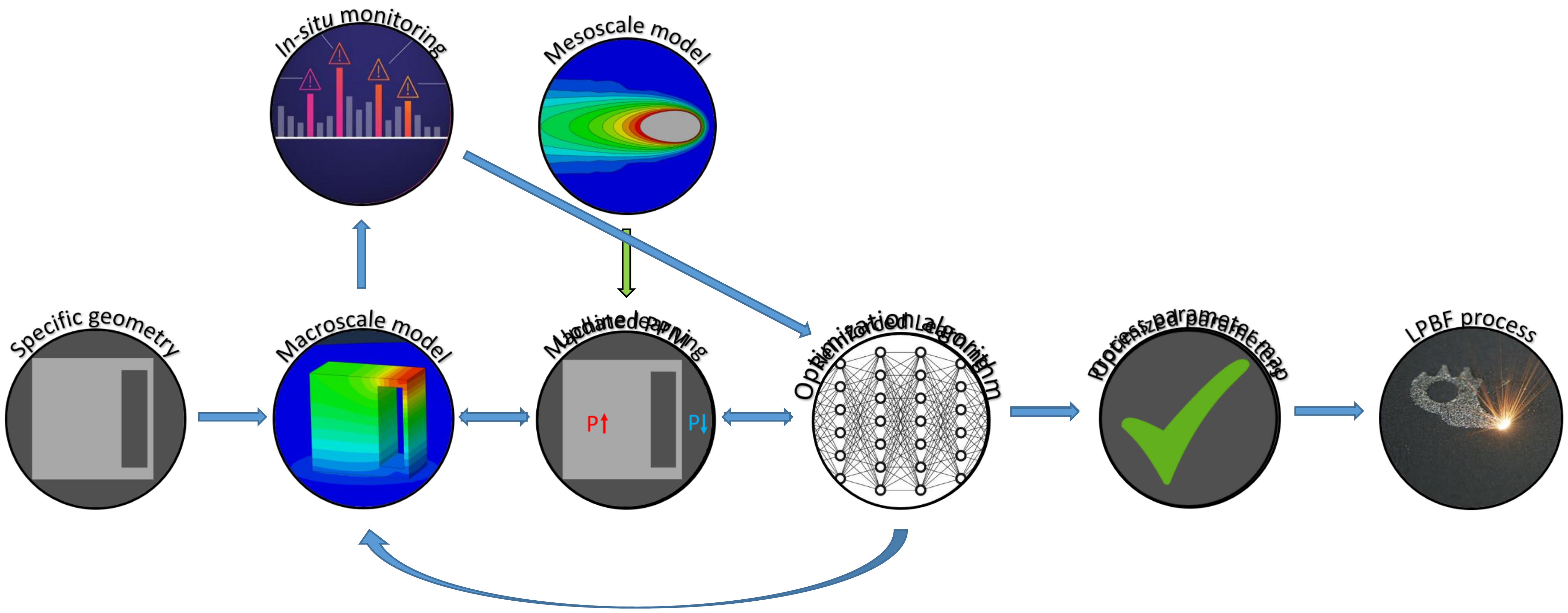
Eutectic AuGe alloy previously cooled at 10 000 K/s (ballistic) – heating rate 5 K/s

Project work flow

Core workflow

Verification/improvement

Training – A priori

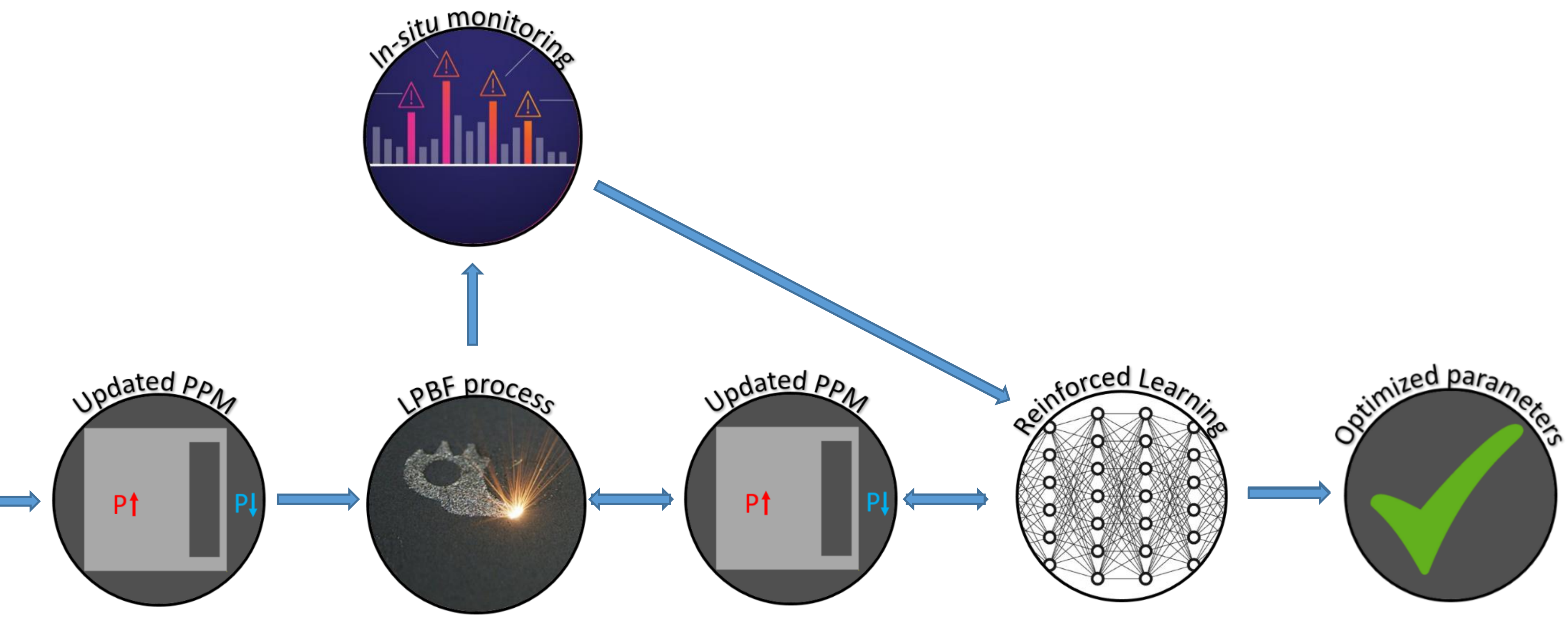


Project work flow

Core workflow

Verification/improvement

Training – A priori



Fast optimization of additively manufactured metallic parts with a combination of adaptive feedforward control and numerical simulation (SMARTAM)

Academic Partners:

R. Logé (EPFL), C. Leinenbach & K. Wasmer (Empa), S. Van Petegem (PSI), J. F. Löffler (ETHZ)

Industrial Partners:

PX Group, Heraeus Materials, Patek Philippe, Swatch Group

Potential other industrial partners:
Richemont-Varinor, Rolex SA