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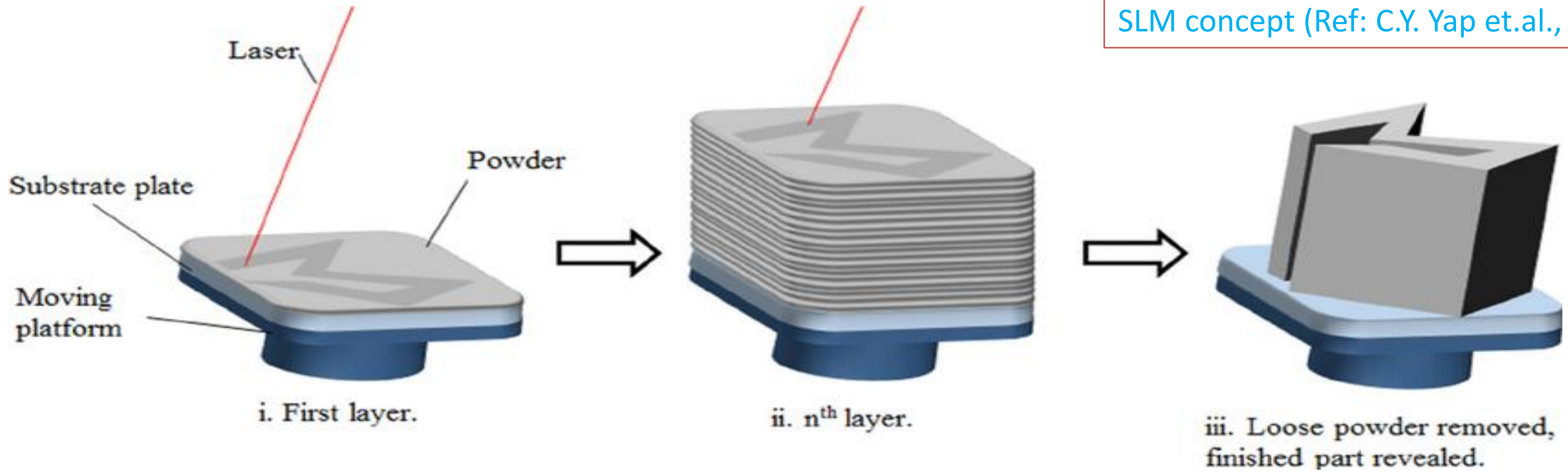
COMSOL CONFERENCE 2019 BOSTON

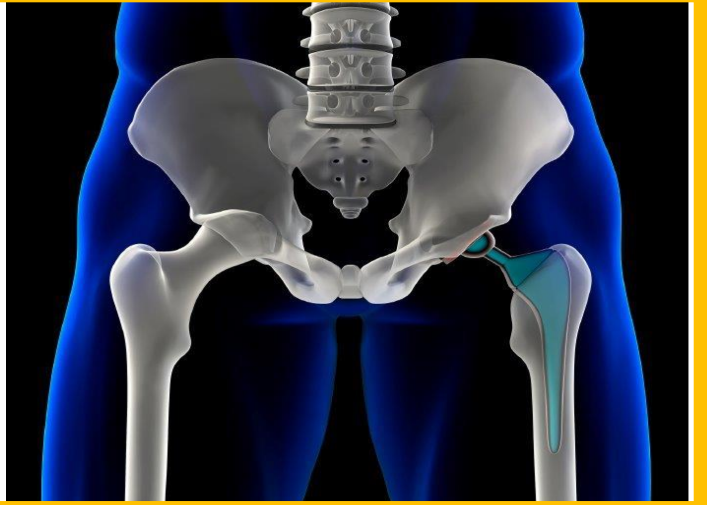
Finite elements modelling and simulation tools to investigate Selective Laser Melting process and materials 3D-printed.

Introduction to SLM process

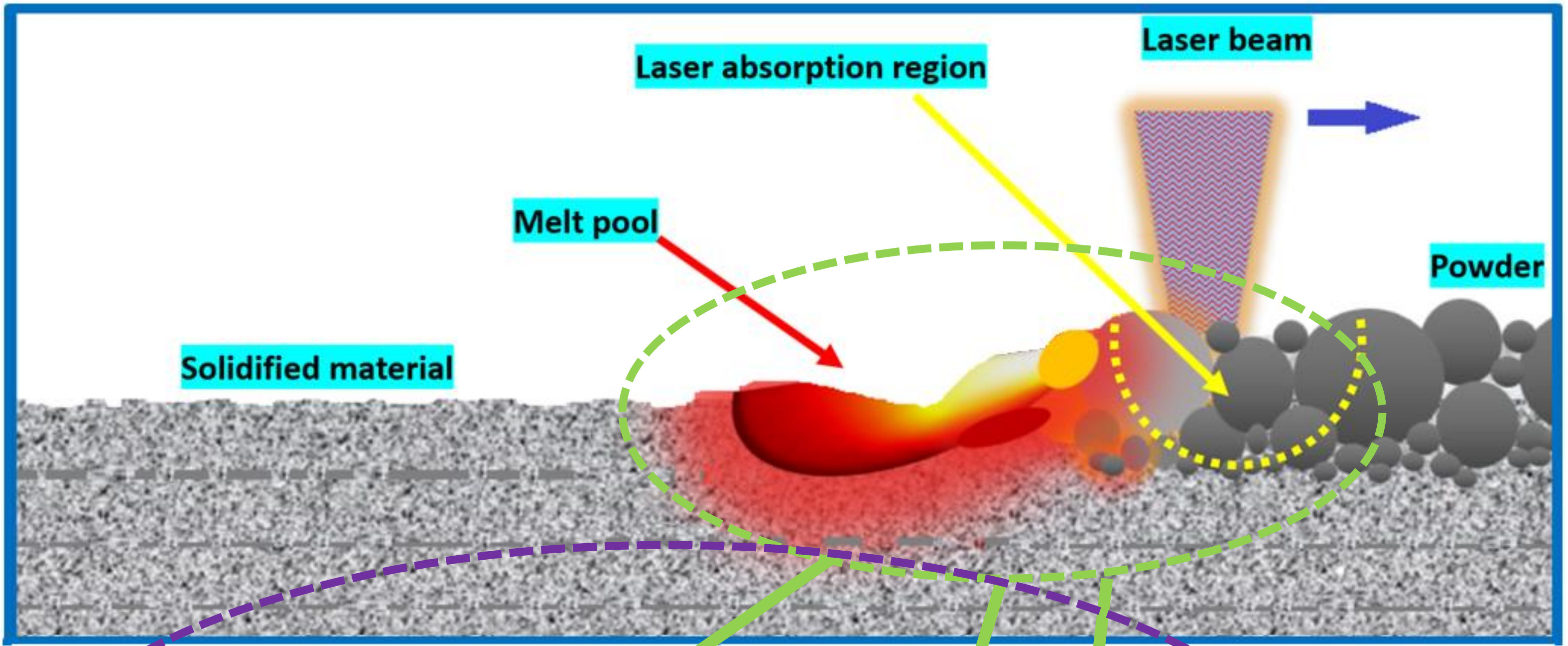
SLM concept (Ref: C.Y. Yap et.al., 2005)



SLM applications …flexibility in design



Introduction to SLM process



Model of laser absorption

Model of T-profile estimation

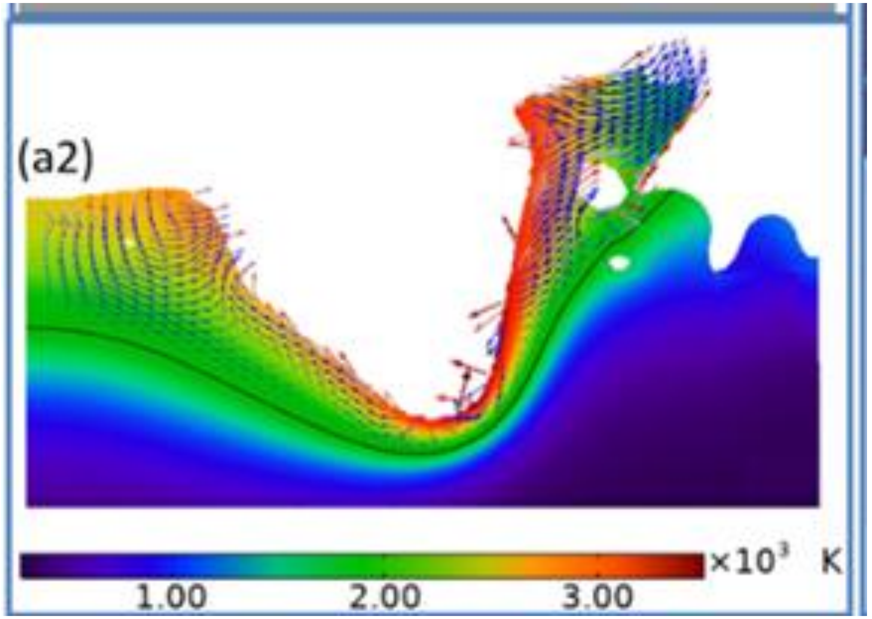
Model of mass transfer

- ❑ Difficult / impossible to measure accurately some process parameters with currently available technologies
- ❑ Expensive experiment: try-and-error method is not favored
- ❑ **Simulation is an important tool**

The use of the simulation model in real engineering situation

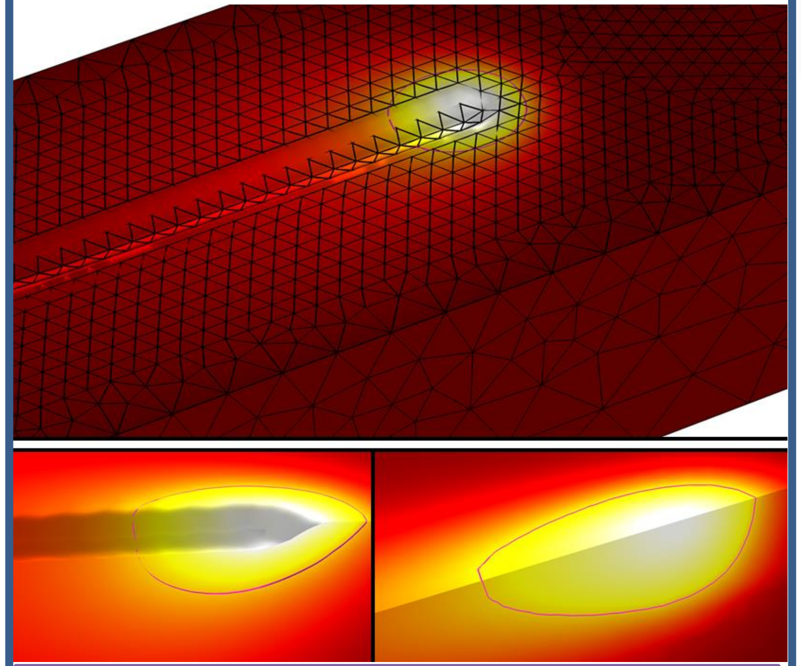
Introduction: Different levels of approximation

Approximate the granular nature of powder



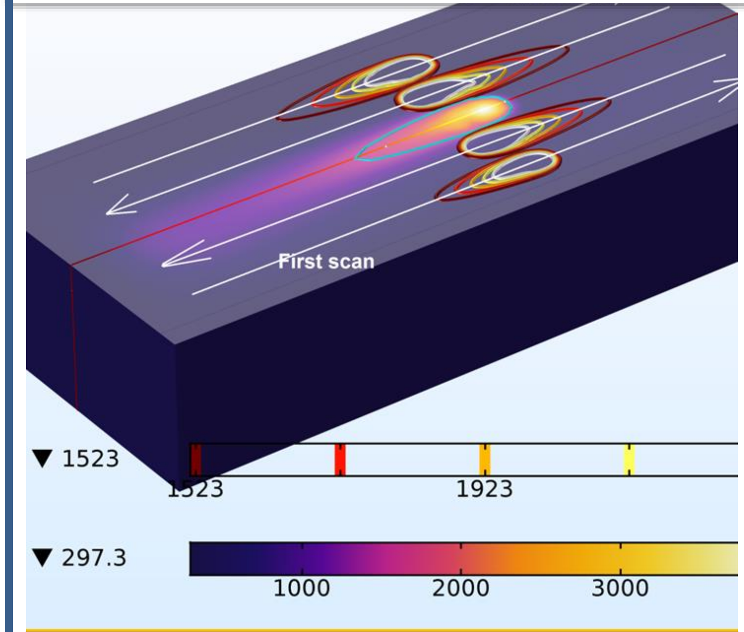
- High computation cost/time
- Differ from real powder bed
- Particular case
- Good for studying porosity or roughness of printed parts

Deformed geometry-moving mesh



- High computation cost/time
- Generalized study
- Good for studying roughness of printed parts

Indirect modelling of volume shrinkage and mass transfer without geometry change

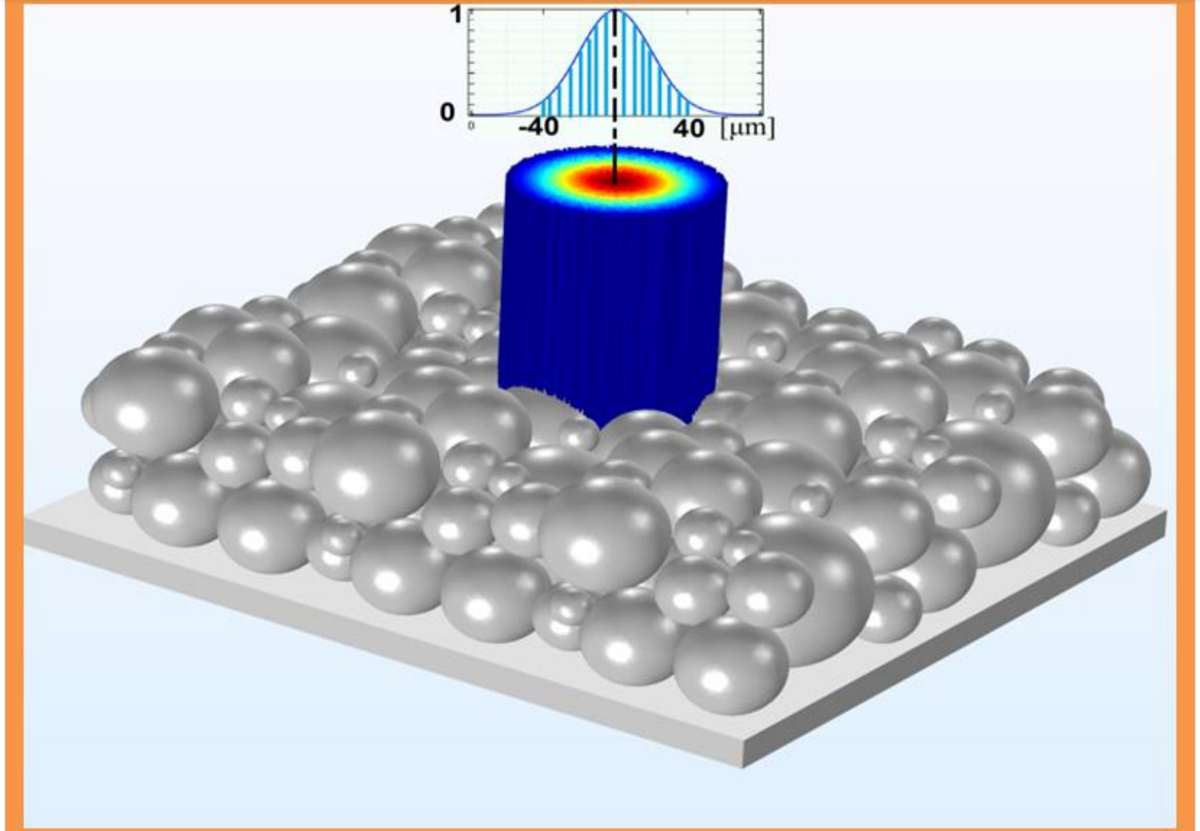


- Low computation cost/time
- Generalized printing quality
- Melt pool size, cooling curve, scanning patterns, multiple layers…
- Adjust the size of powder layer and printed layer

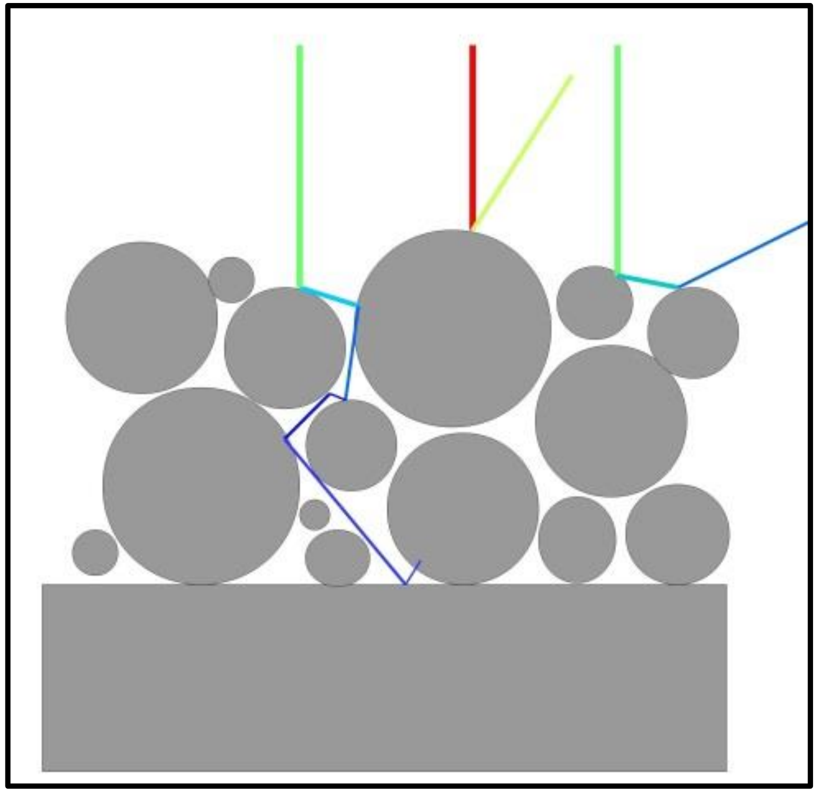
Simulated temperature-profile is comparable in the 3 approximations

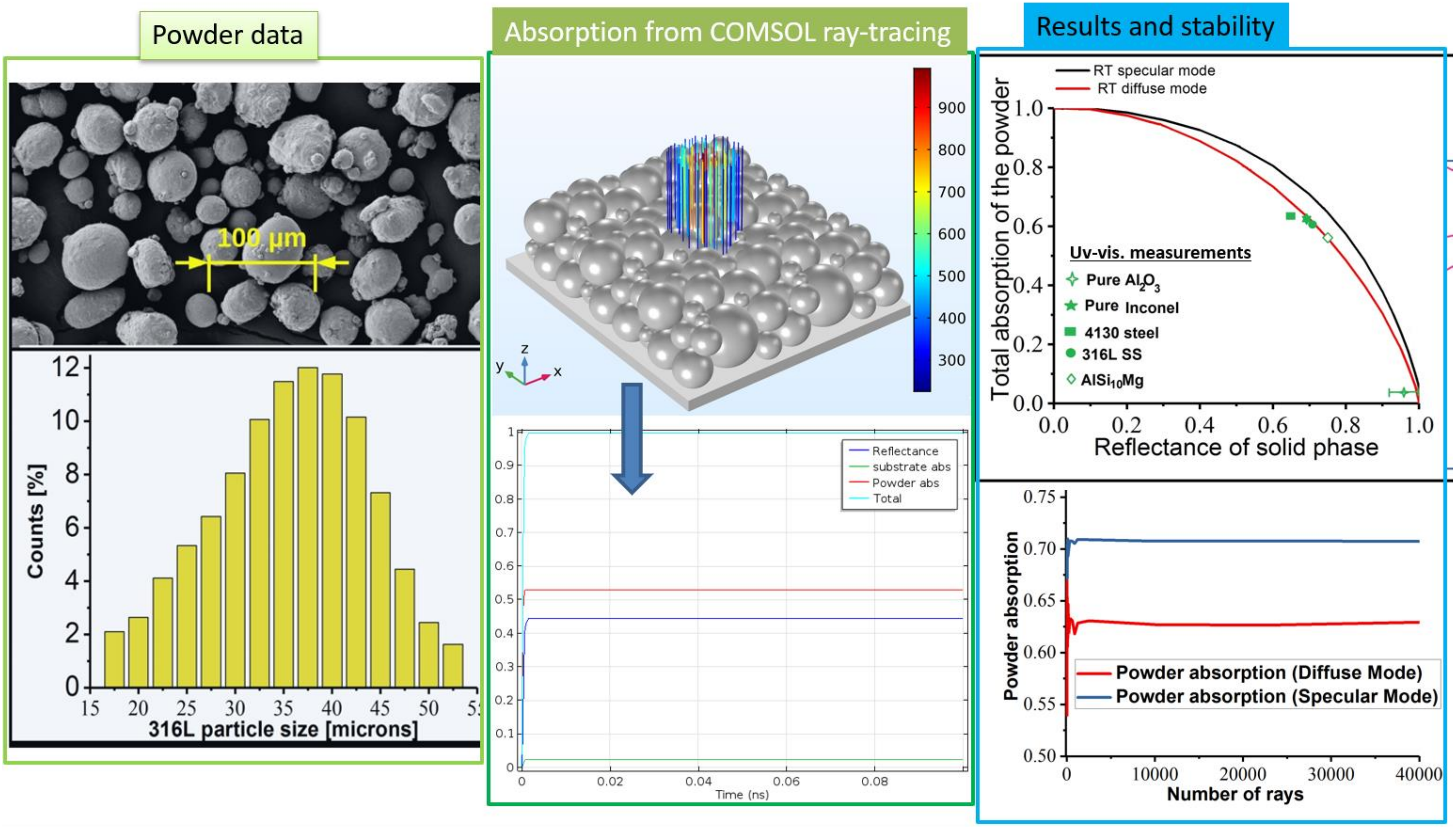
1. Laser absorption: Ray-tracing

Real powder, real static beam



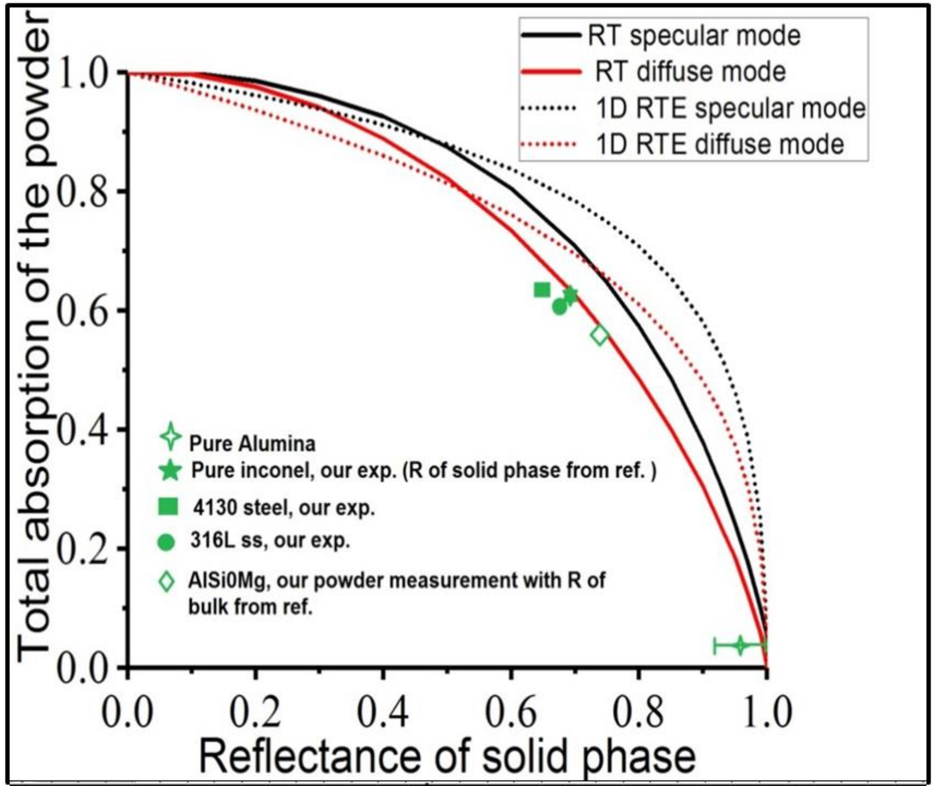
Illustration

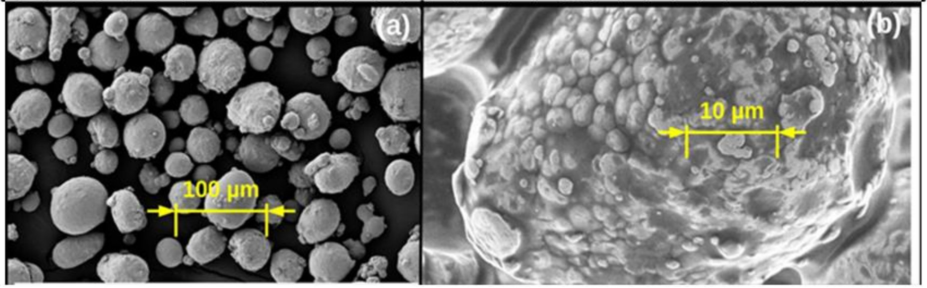


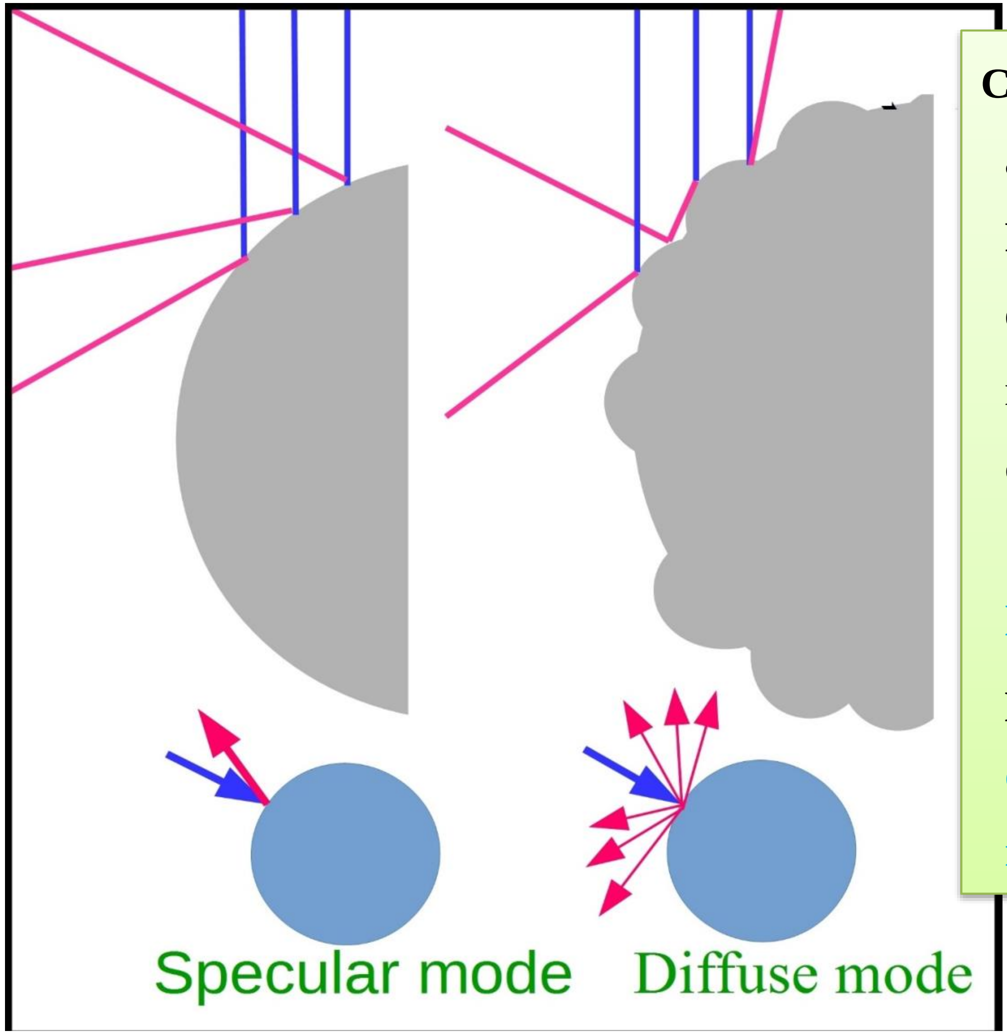


Powder data
100 µm
Counts [%]
316L particle size [microns]
Absorption from COMSOL ray-tracing
Reflectance
substrate abs
Powder abs
Total
Time (ns)
Results and stability
RT specular mode
RT diffuse mode
Total absorption of the powder
Reflectance of solid phase
Uv-vis. measurements
Pure Al_2O_3
Pure Inconel
4130 steel
316L SS
$AlSi_{10}Mg$
Powder absorption
Powder absorption (Diffuse Mode)
Powder absorption (Specular Mode)
Number of rays

Ray-tracing vs analytical solution of the Radiation Transfer Equation (RTE)







Comparison of total absorption obtained by RT, 1D-RTE and experiment: High resolution SEM image of commercial powder used in SLM reveals **non-mirror-like surface of powder particles justifying the deviation from specular reflection**

2. Model of T-profile estimation

Heat transfer

$$\rho c_p \frac{\partial T}{\partial t} + \rho c_p u.\nabla T - \nabla(k\nabla T) = Q$$

$$k\left[\frac{\partial T}{\partial z}\right]_{z=H} = \varepsilon\sigma\left(T_o^4 - T^4(x,y,H,t)\right) + h\left(T_o - T(x,y,H,t)\right)$$

$$T(x,\ y,\ z,\ t)|_{t=0} = T_0$$

Mass transfer

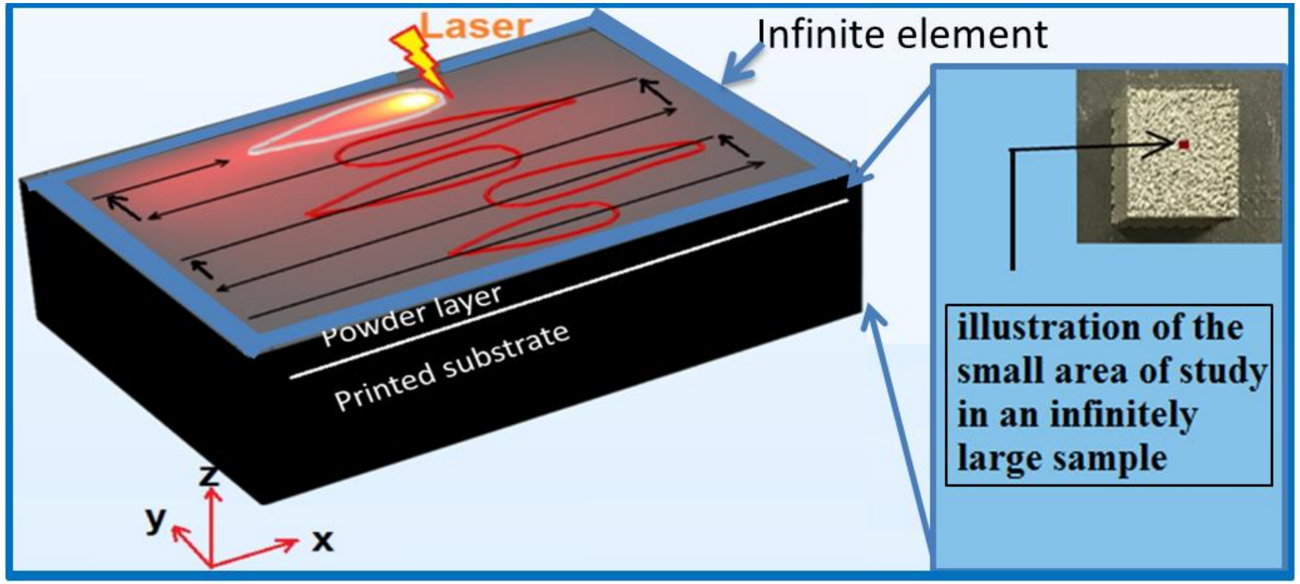
$$\begin{cases} \rho\frac{\partial u}{\partial t} + \rho(u.\nabla)u = \nabla\left[-PI + \mu\left((\nabla u + (\nabla u)^T)\right)\right] + \rho g + F. \\ \rho\nabla.(u) = 0. \end{cases}$$

Laser energy source from Ray-tracing and distribution

$$Q = (\alpha_A)\frac{2P}{\pi l(\alpha_r r)^2}\exp\left\{\frac{2[(x-p_1(t))^2 + (y-p_2(t))^2]}{(\alpha_r r)^2}\right\} \times u(z)$$

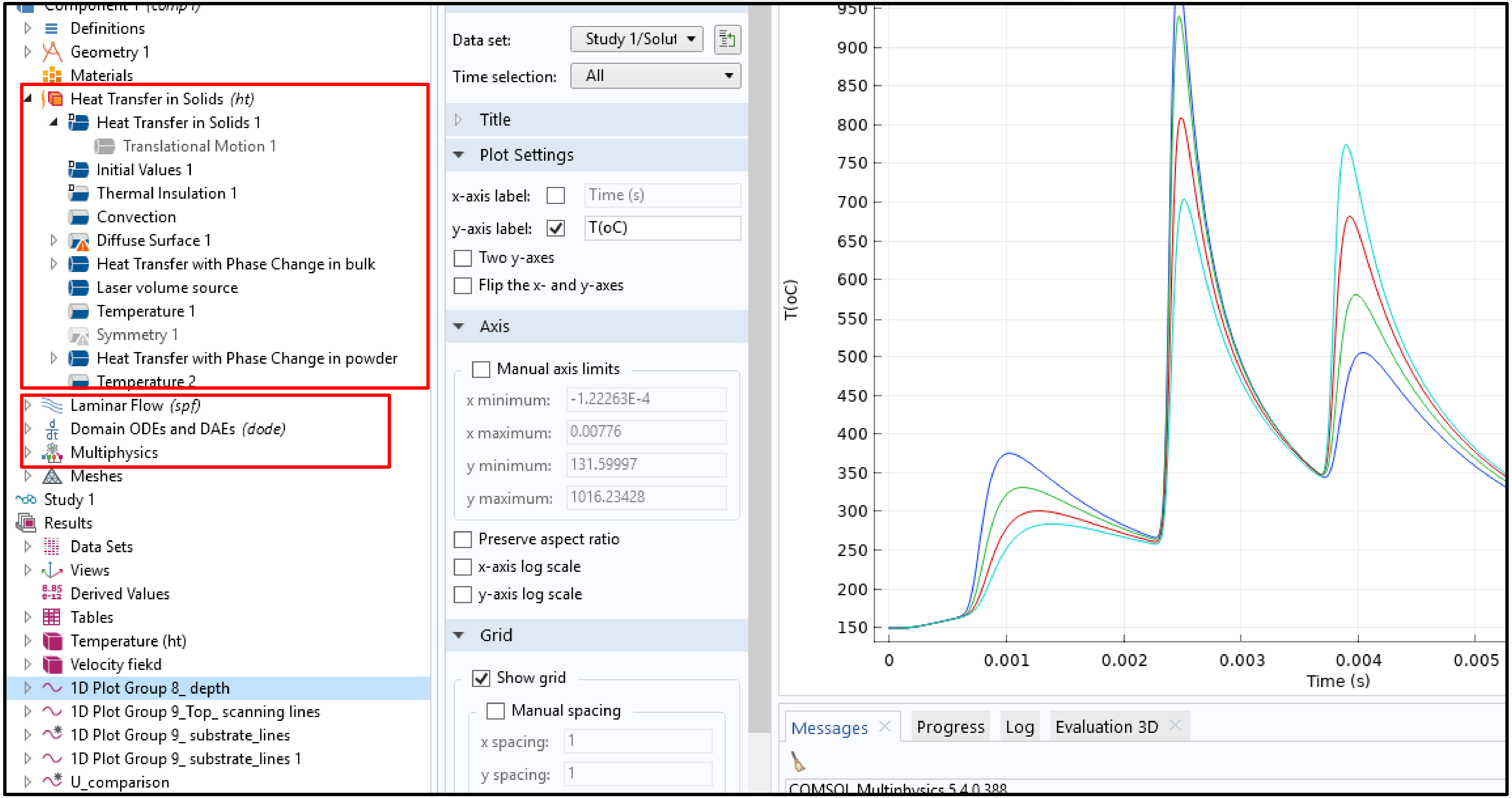
From Ray-tracing

- $F^{Marangoni} = \nabla_s\gamma\,, \quad \gamma = \gamma_0 + \frac{d\gamma}{dT}(T - T_{ref})$
- Recoil pressure during vaporization



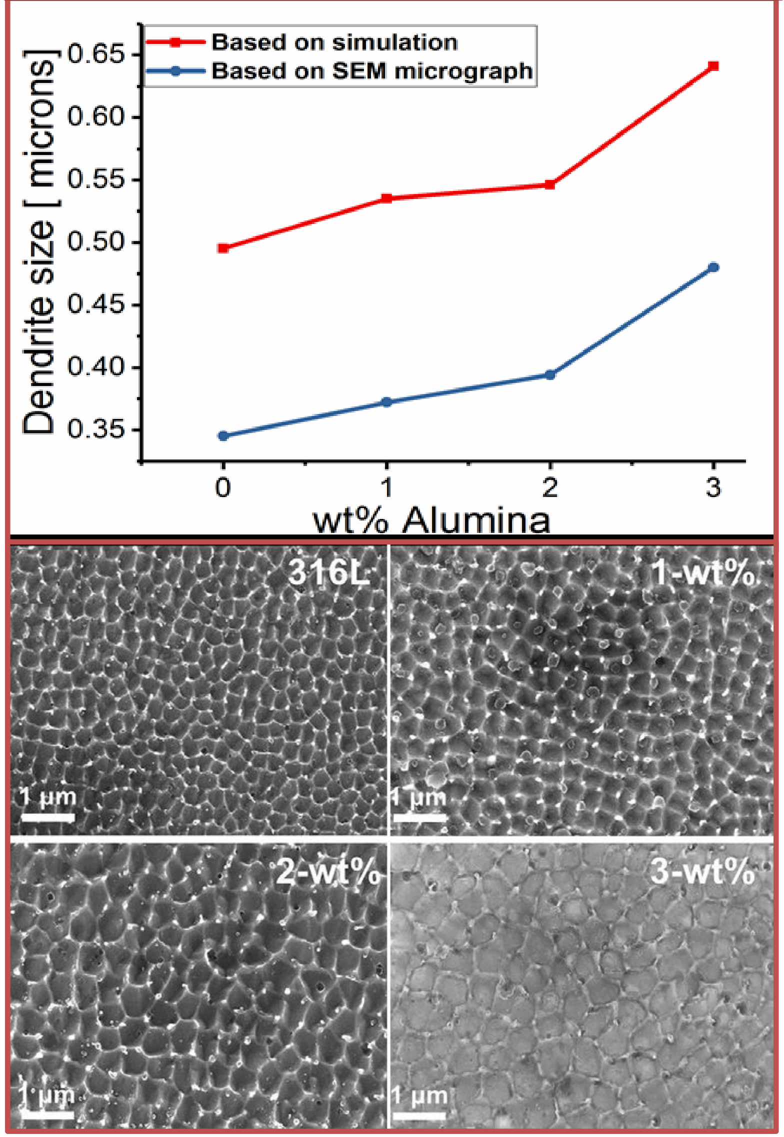
Note: Immediate coupling of ray-tracing

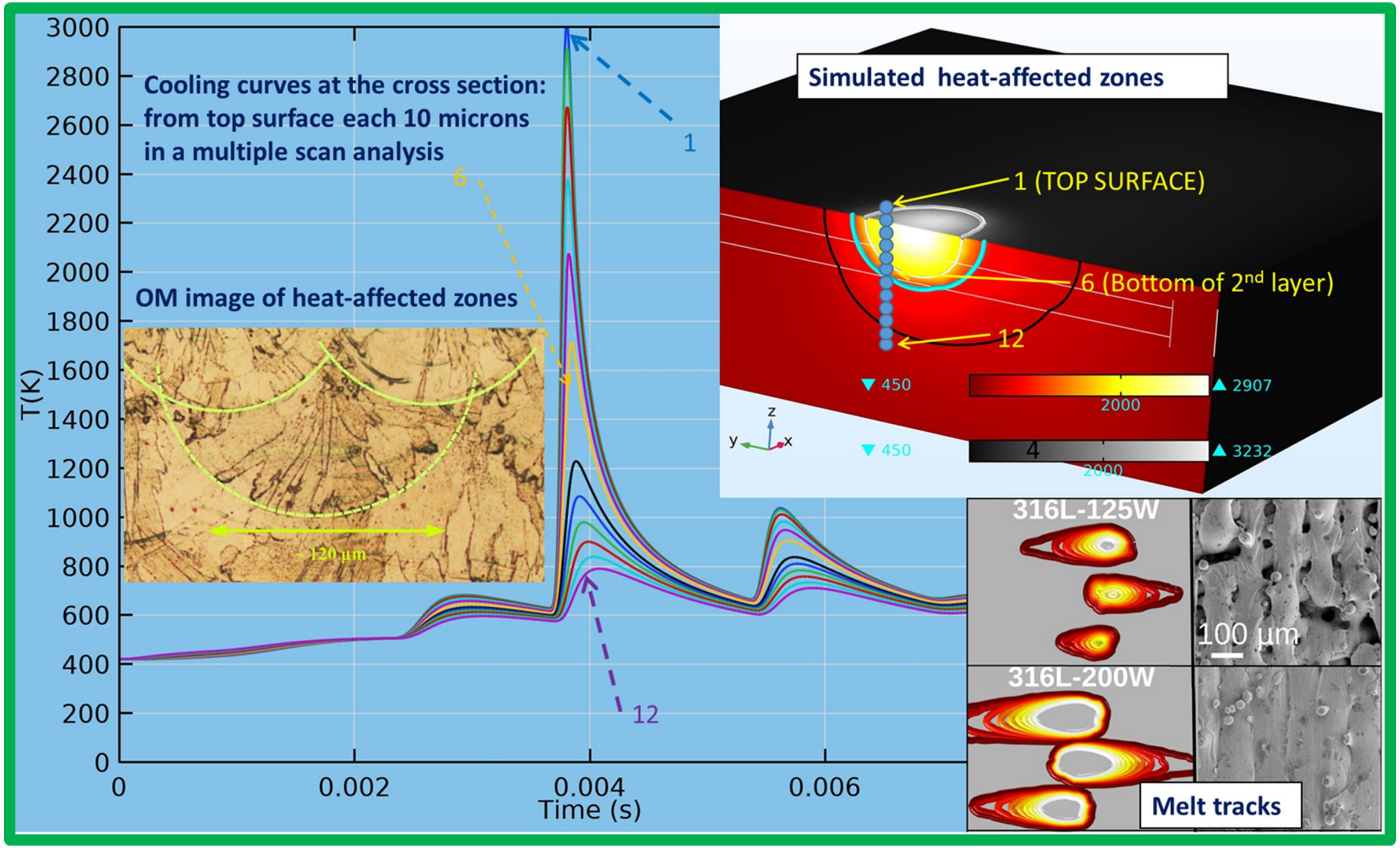
3. COMSOL setting



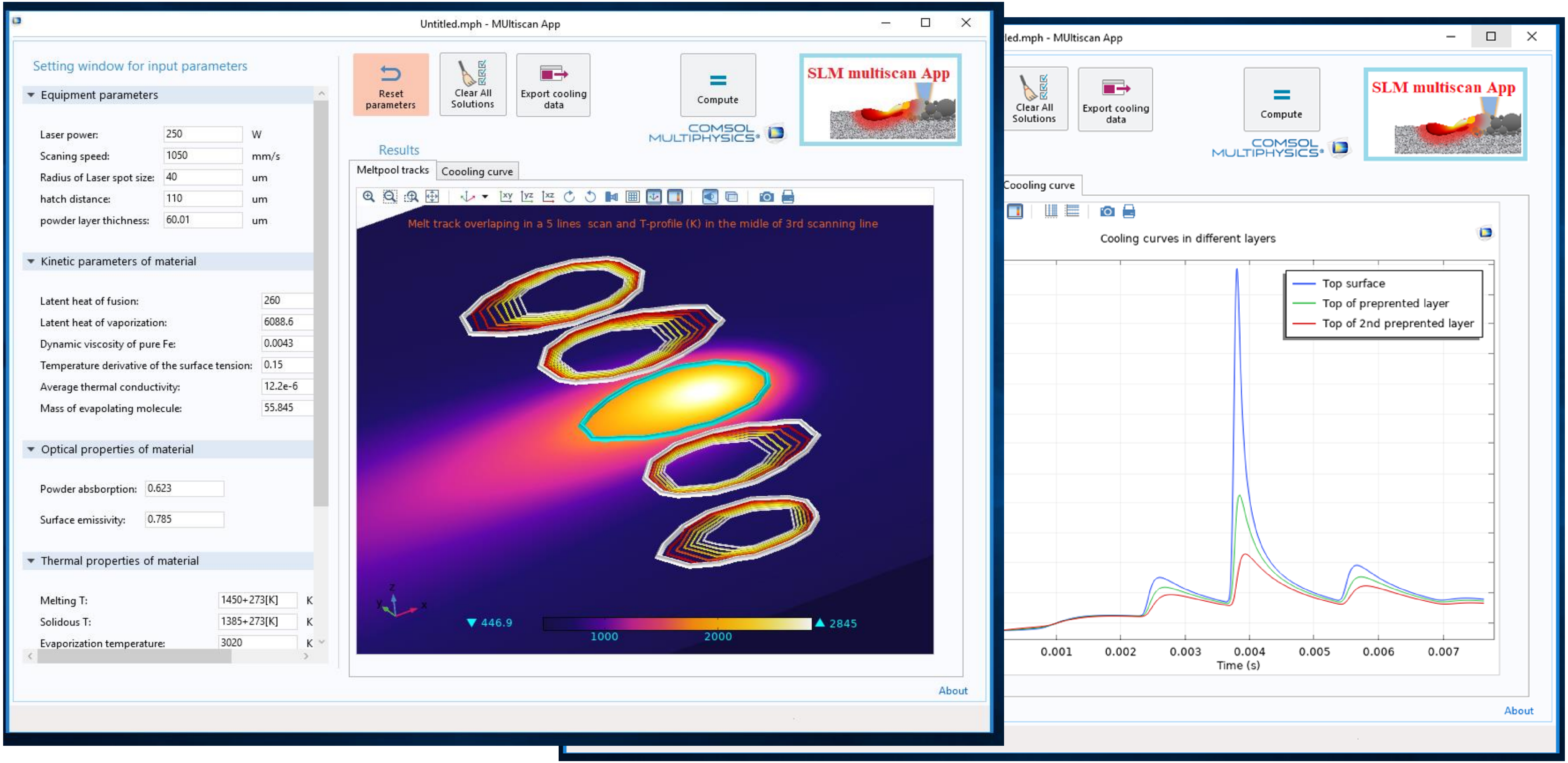
3. Some examples using SLM simulation

316L-Alumina composite: control of grain size



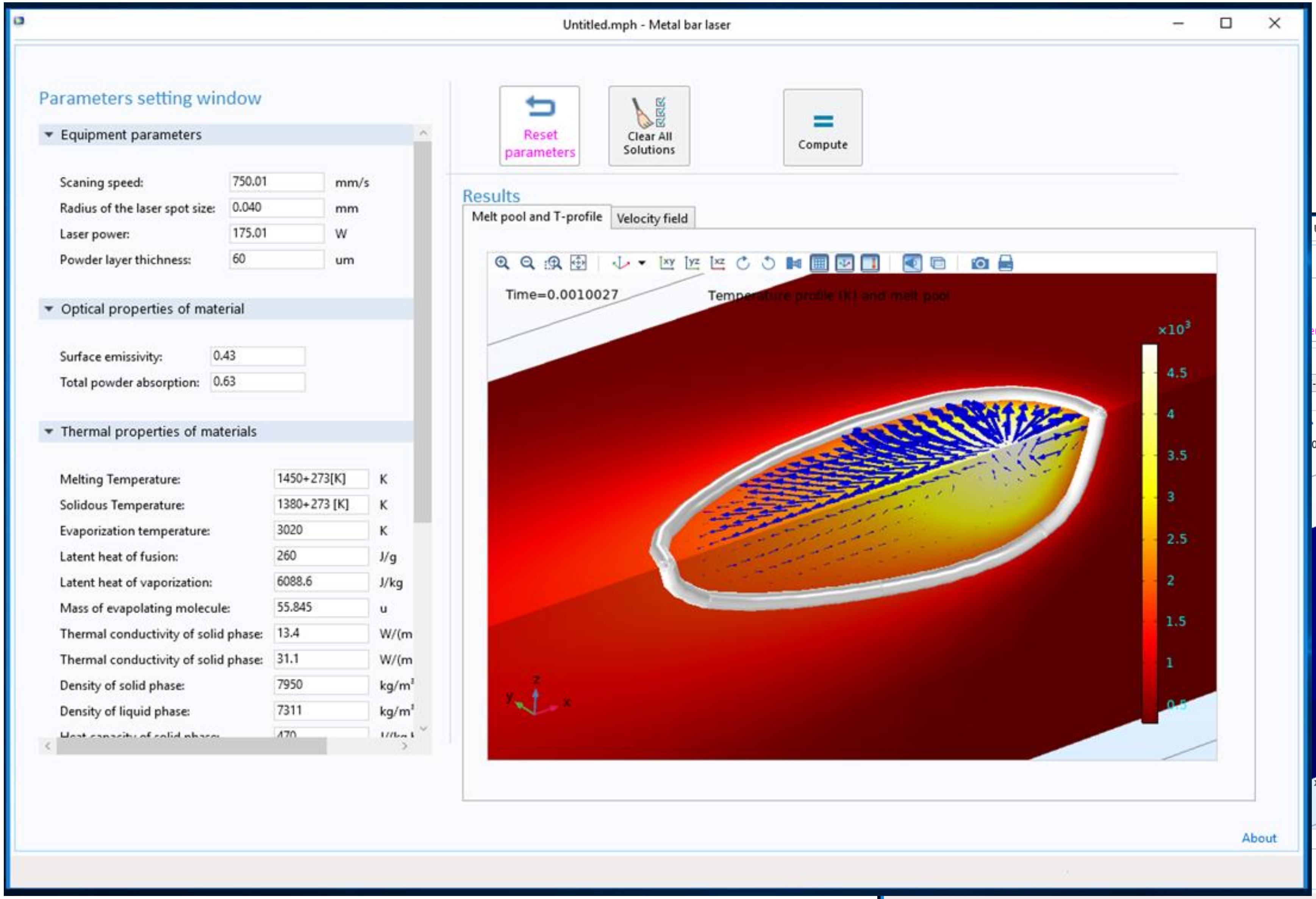


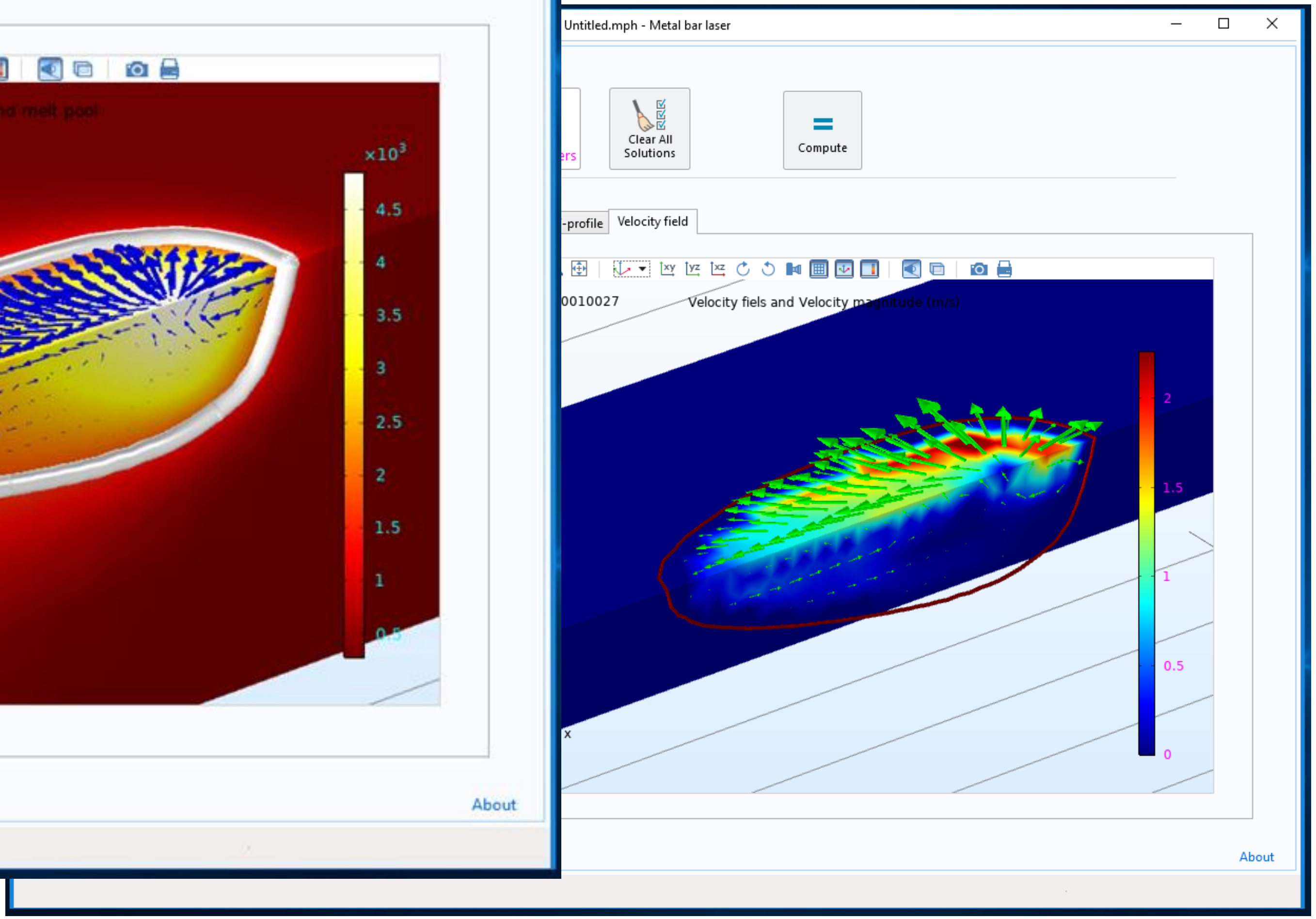
4. COMSOL App – Multiple scanning lines



COMSOL App – Single scan

<u>Note:</u> Melt pool size usually increases a bit from 1 to 2nd line due to heat accumulation but it normally stabilizes at the 3rd line. One should know this while using this single scan model





Summary

- Compared to experimental measurements of laser absorption in commercial powders used in SLM, ray-tracing diffuse mode gives the best approximation.

- The results of T-profile simulation (overlapping of molten truck, molten pool size, cooling information) agree with experiment .

- SLM being a relatively complex process, COMSOL Apps is useful for users without strong background in modelling.