Heating of a beam dechirper for the XFEL

TECHNISCHE UNIVERSITÄT DARMSTADT

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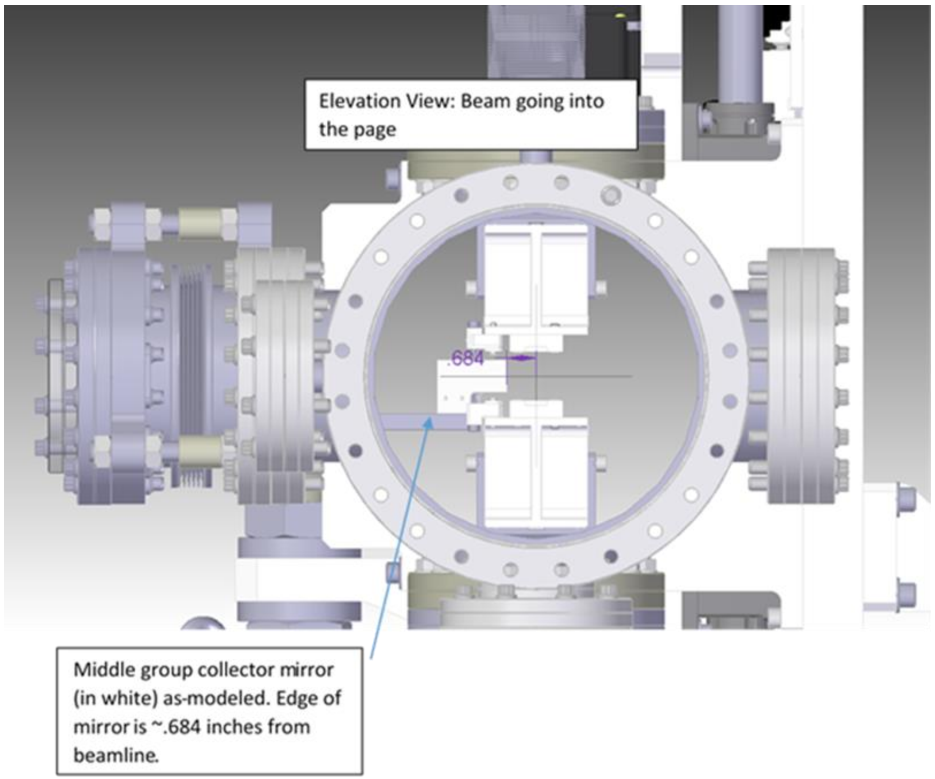
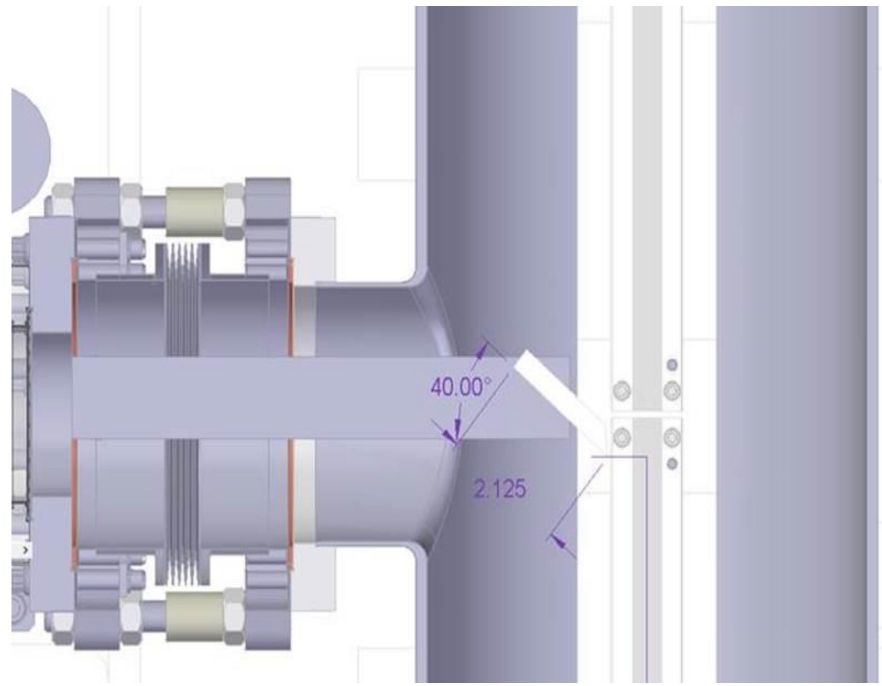
- Dechirper Description
- Simulation Procedure
- Constant Beam Current Simulations
- Bunch Train Simulations Simulations
- Summary & Conclusion

Dechirper Description

- Chamber geometry

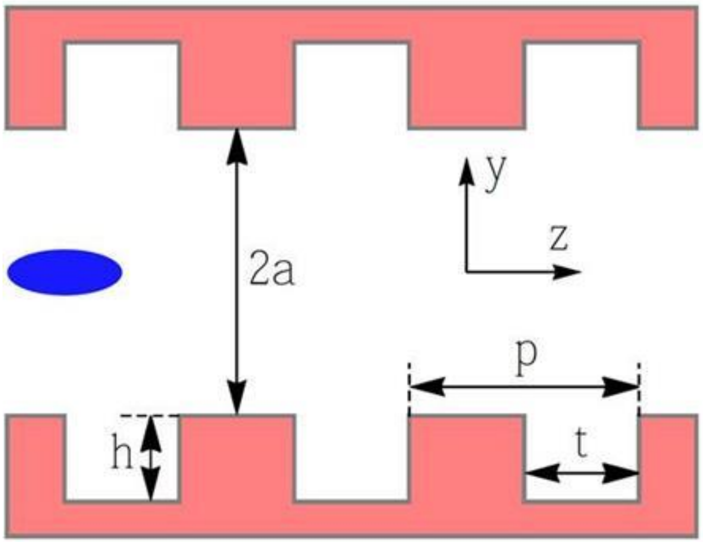




Courtesy: A. Fisher, SLAC

Dechirper Description

- Dechirper geometry



Parameter	Value	Unit
Depth, *h*	0.5	mm
Gap, *t*	0.25	mm
Period, *p*	0.5	mm
Half aperture, *a*	0.7	mm
Half width, *w*	6	mm
Length, *L*	2	m

K. Bane, G. Stupakov, E. Gjonaj, Joule heating in a flat dechirper
Phys. Rev. Accel. Beams 20, 2017

Dechirper Description

- Power loss estimates

$$P = Q^2 k_{loss} f_{rep}$$

SLAC

Q =300pC, f_{rep} =100kHz, $l_z = 60\mu\text{m}$

	$P_{heat,ana}$ [W/m]	$P_{heat,num}$ [W/m]
Two plates, a=0.7 mm	5	21
Single plate, b=0.25 mm	14	24

The EXFEL

Q =500pC, f_{rep} =27kHz, $\sigma_z = 25\mu\text{m}$

	$P_{heat,ana}$ [W/m]	$P_{heat,num}$ [W/m]
Two plates, a=0.7 mm	4	15
Single plate, b=0.25 mm	10	18

Courtesy: I. Zagorodnov, DESY

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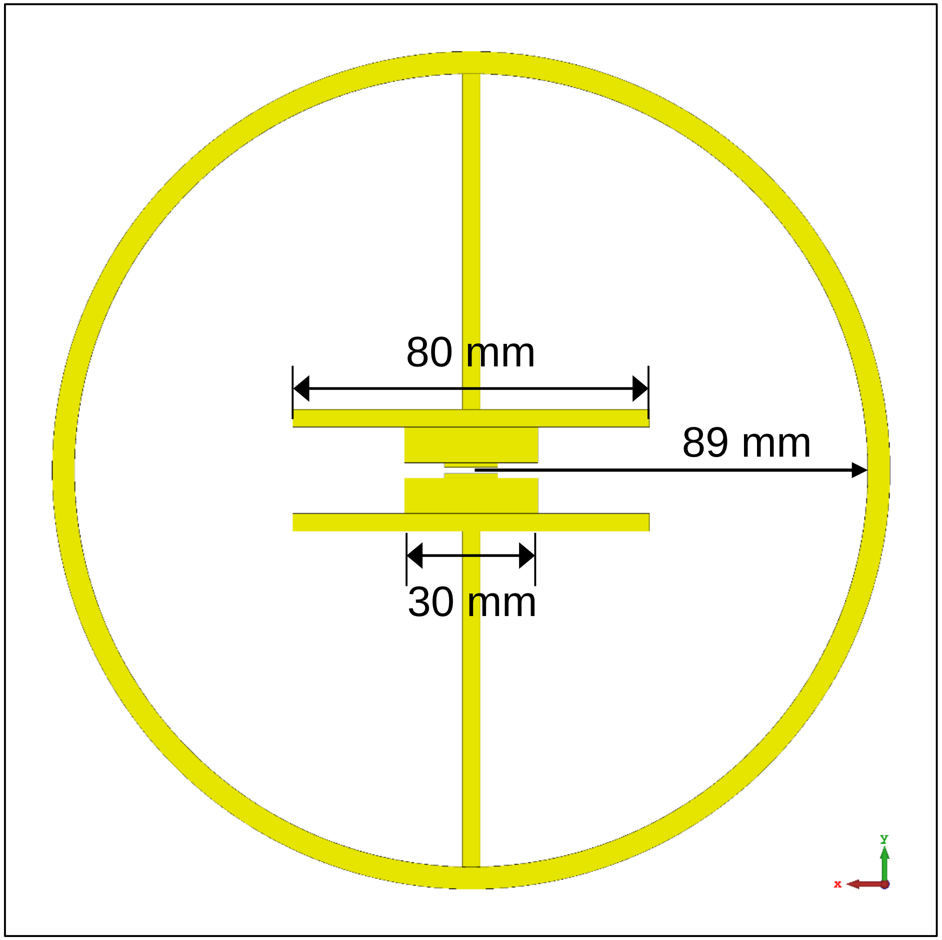
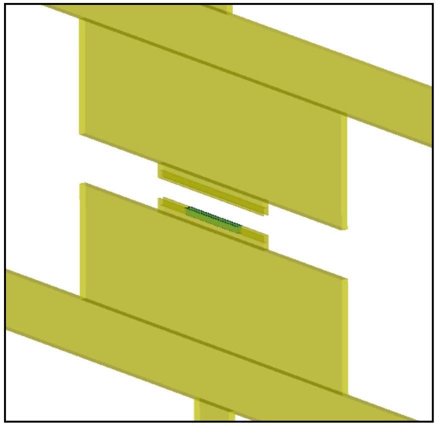
Simulation Procedure

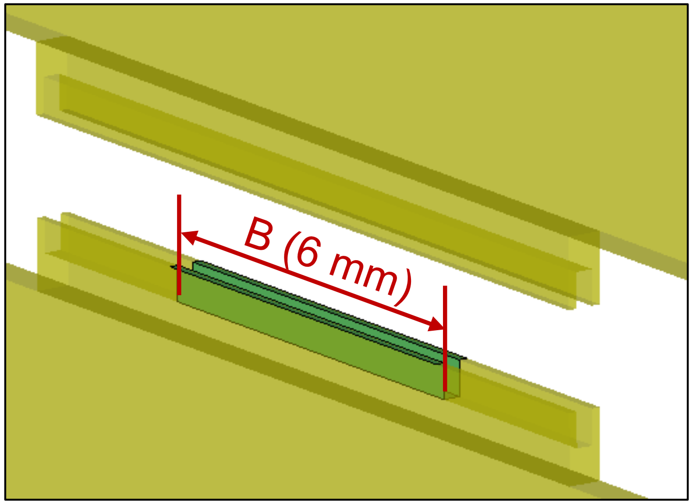
- Simulation geometry





Material:

Pure aluminum

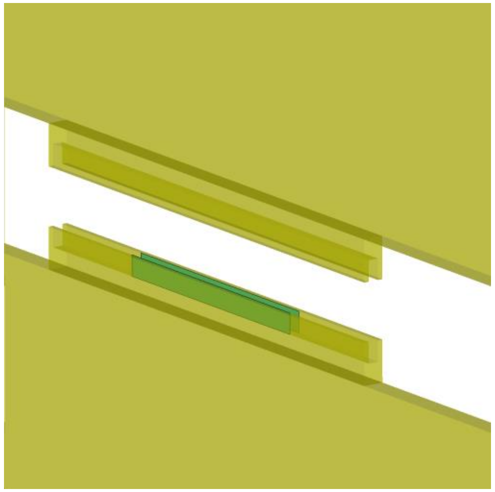


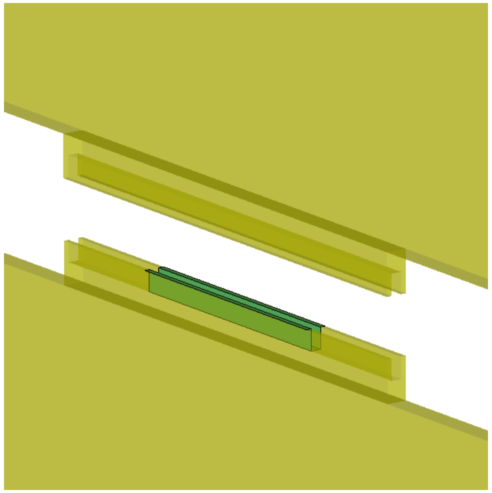
Simulation Procedure

Configuration 1:
Losses on top
surface only

Configuration 3:
Losses on bottom
surface only

Configuration 2:
Losses on side
surface only





Configuration 4:
Losses on all
surfaces

Simulation Procedure

Constant beam current	Train of bunches
Source location (top, sides, bottom, all)	Only top (highest temperature)
Source width (0.6…12 mm)	Source width (0.6…12 mm)
Boundary conditions (isothermal, radiation)	Only isothermal
Emissivity (0.05…1)	-
Power (5…25 W/m)	-

- No beam structure
- Constant loss power

- 10 trains / second (each train contains 2700 bunches with rate 4.5 MHz)
- Pulsed loss power

Simulation Procedure

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- Transient heat distribution in metal
  - Heat conduction equation:

$$\rho c_p \frac{\partial T}{\partial t} - \nabla \cdot (k \nabla T) = \dot{q}_V$$

- Heat radiation at outer chamber-surface
  - Stefan–Boltzmann law:

$$\dot{q}_A = \varepsilon\sigma(T^4 - T_0^4)$$

    - Only radiation to ambient considered (no surface-to-surface radiation)

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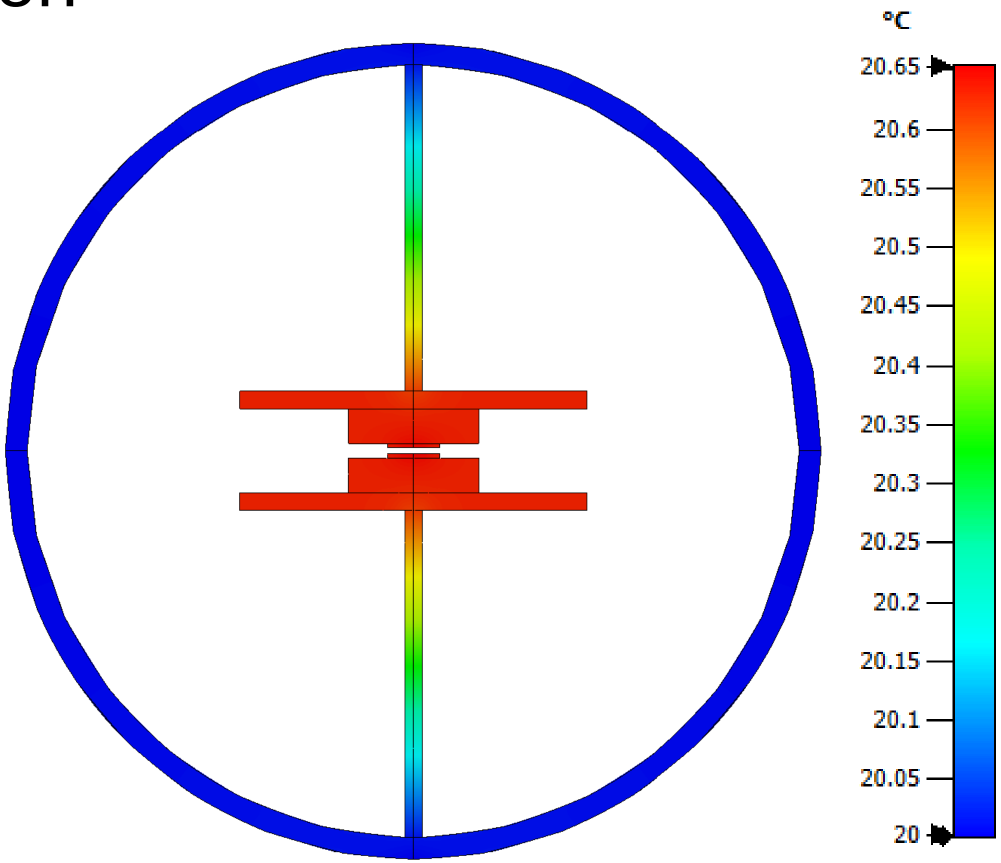
Constant Beam Current Simulations

- Temperature distribution
  - Loss power: 15 W/m
  - Source width: 6 mm
  - Ambient temperature: 20 ℃
  - Isothermal outer boundary
  - Very small temperature increase (~0.7 ℃)



Constant Beam Current Simulations

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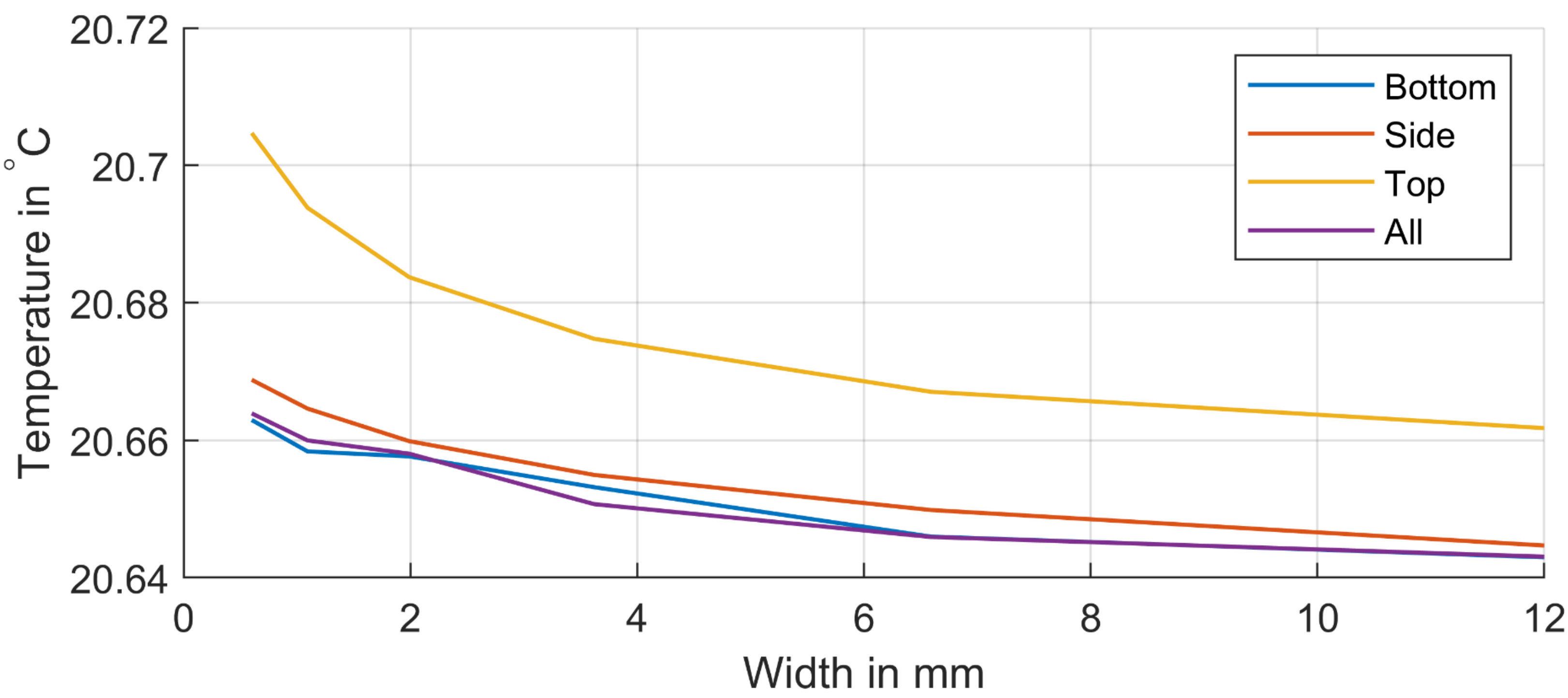
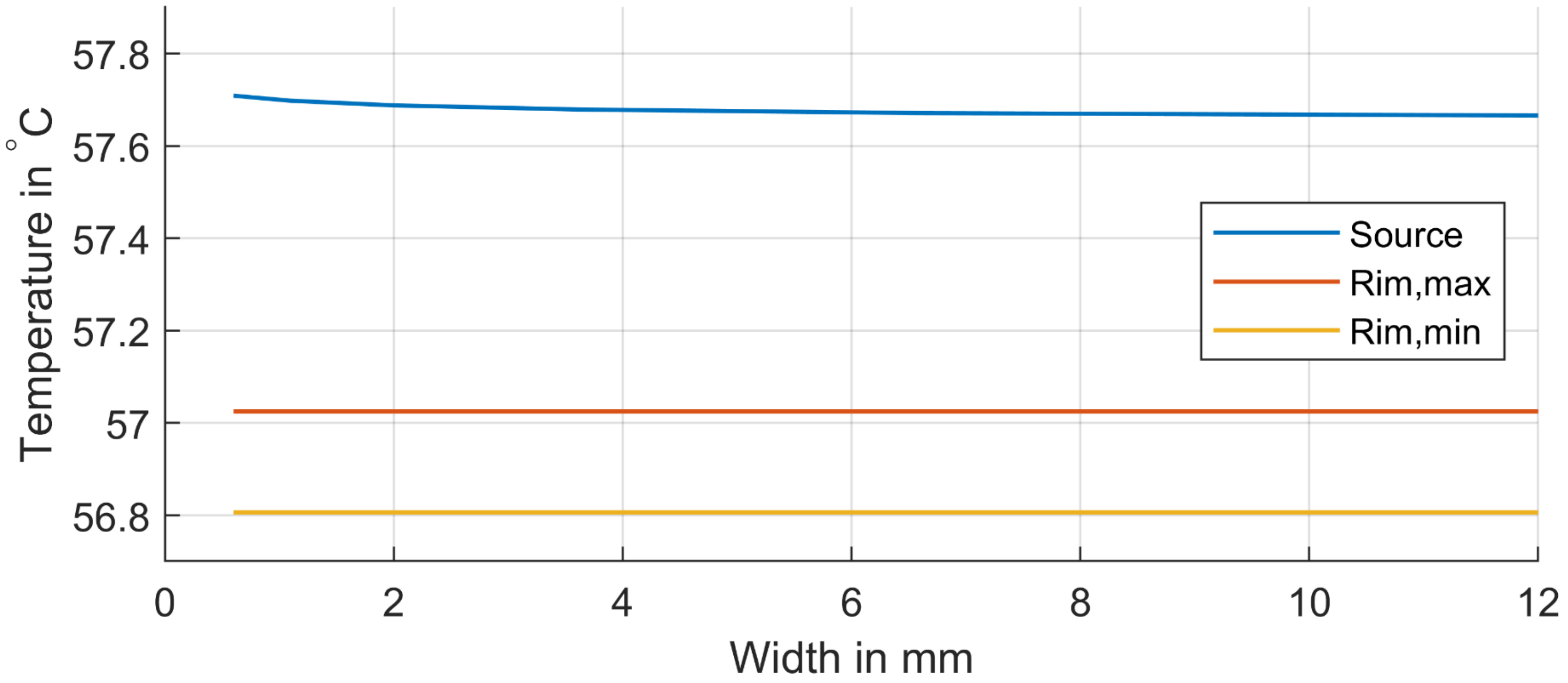
- Influence of source width



P=15 W/m   boundary=isothermal

Constant Beam Current Simulations

- Influence of boundary condition



P=15 W/m boundary=radiation source=top emissivity=0.1

Constant Beam Current Simulations

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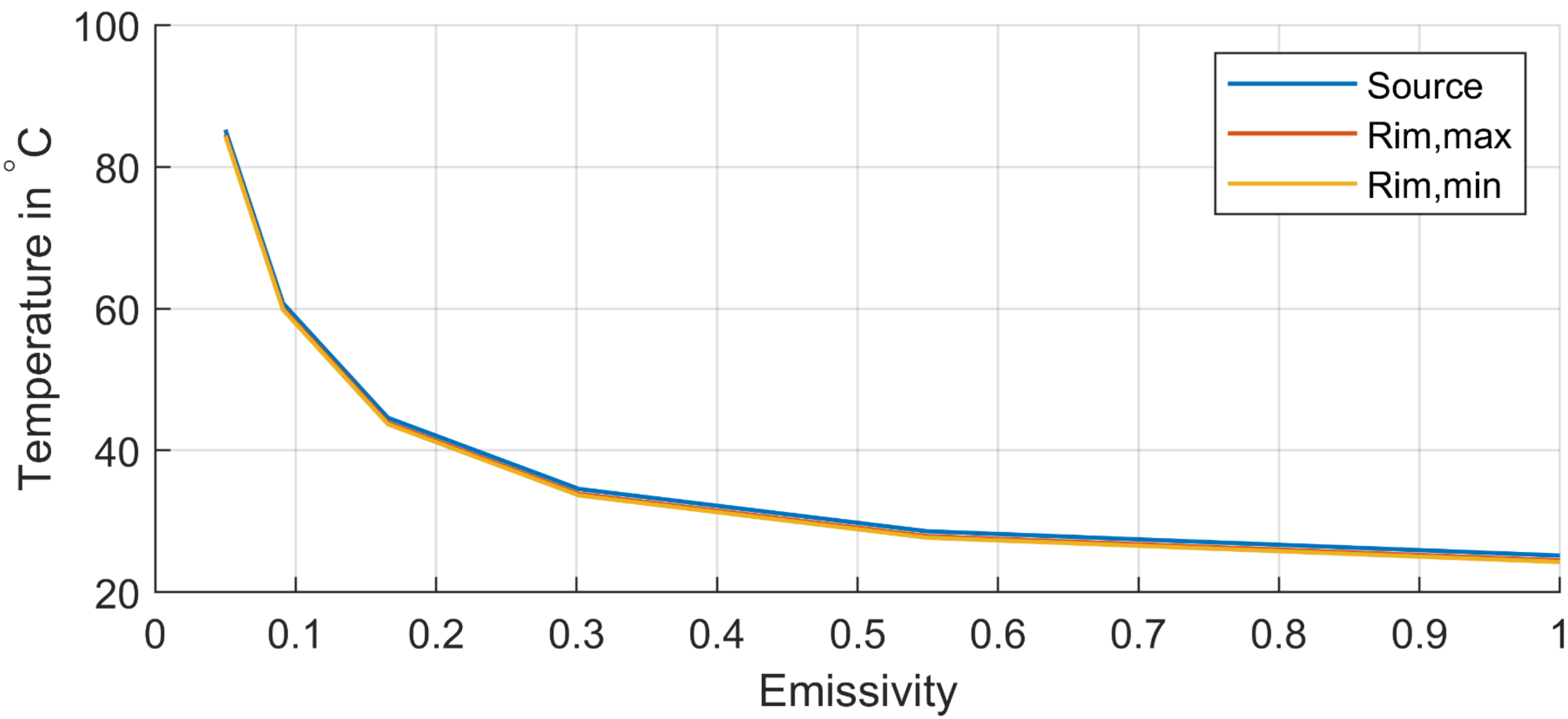
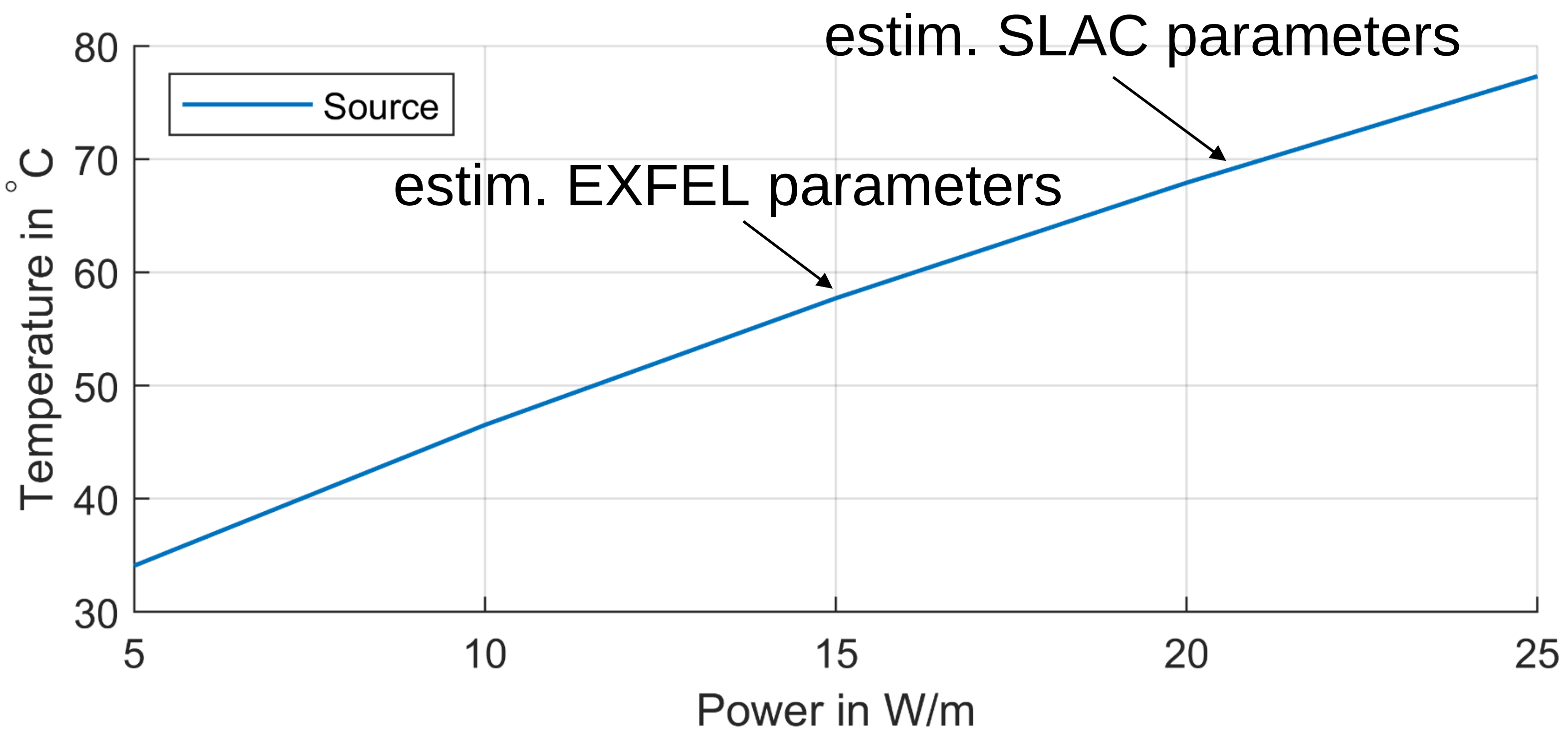
- Influence of (outer) surface emissivity



P=15 W/m boundary=radiation source=top width=0.6 mm

Constant Beam Current Simulations

- Variation with power



boundary=radiation source=top width=0.6 mm emissivity=0.1

Constant Beam Current Simulations

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- Isothermal boundary
  - Very small temperature increase (< 1℃) for all considered parameters
  - Small influence of spatial loss distribution (source location and width)
- Radiation boundary
  - Temperature increases up to 25-90 ℃ (ambient temperature 20 ℃)
  - For aluminum with $\varepsilon = 0.1$ (nominal case), T = 57.7 ℃
  - Strong dependence on emissivity of the outer pipe surface
  - Temperature scales about linear with power
  - Small influence of spatial loss distribution (source location and width)

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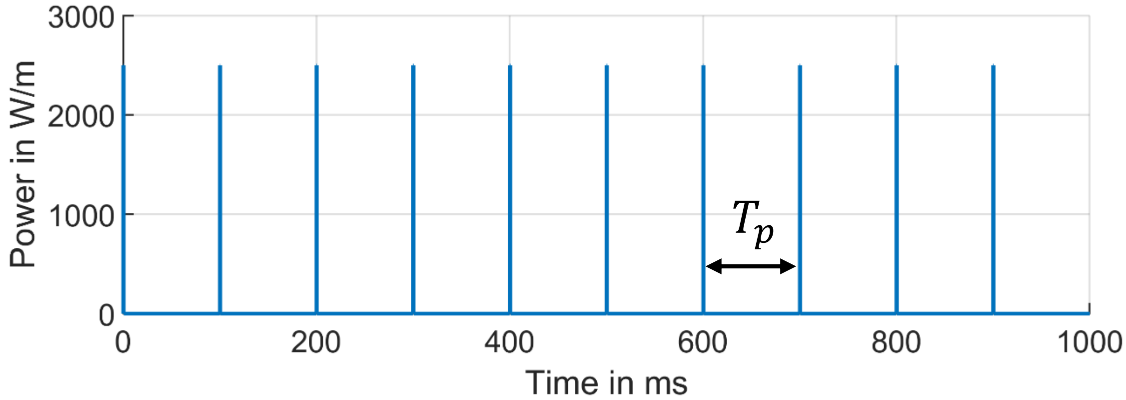
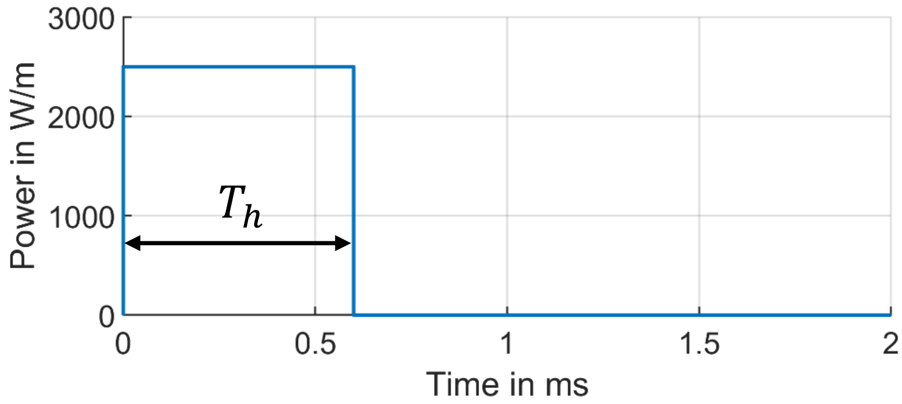
Bunch Train Simulations

- Rectangular signal
- Period time:
  - 10 trains per second
  - $T_p = 0.1\ s$
- Hold time
  - 2700 bunches at 4.5 MHz
  - $T_h = \frac{2700}{4.5\ MHz} = 0.6\ ms$
- Amplitude
  - $P_{mean} = 15\ W/m$
  - $\hat{P} = 2500\ W/m$





Bunch Train Simulations

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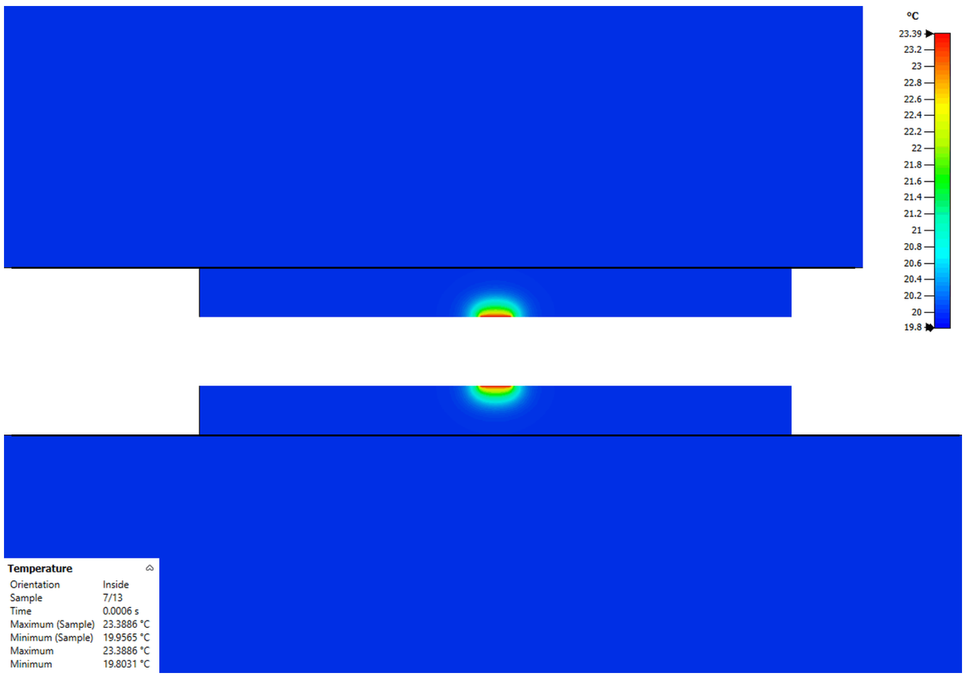
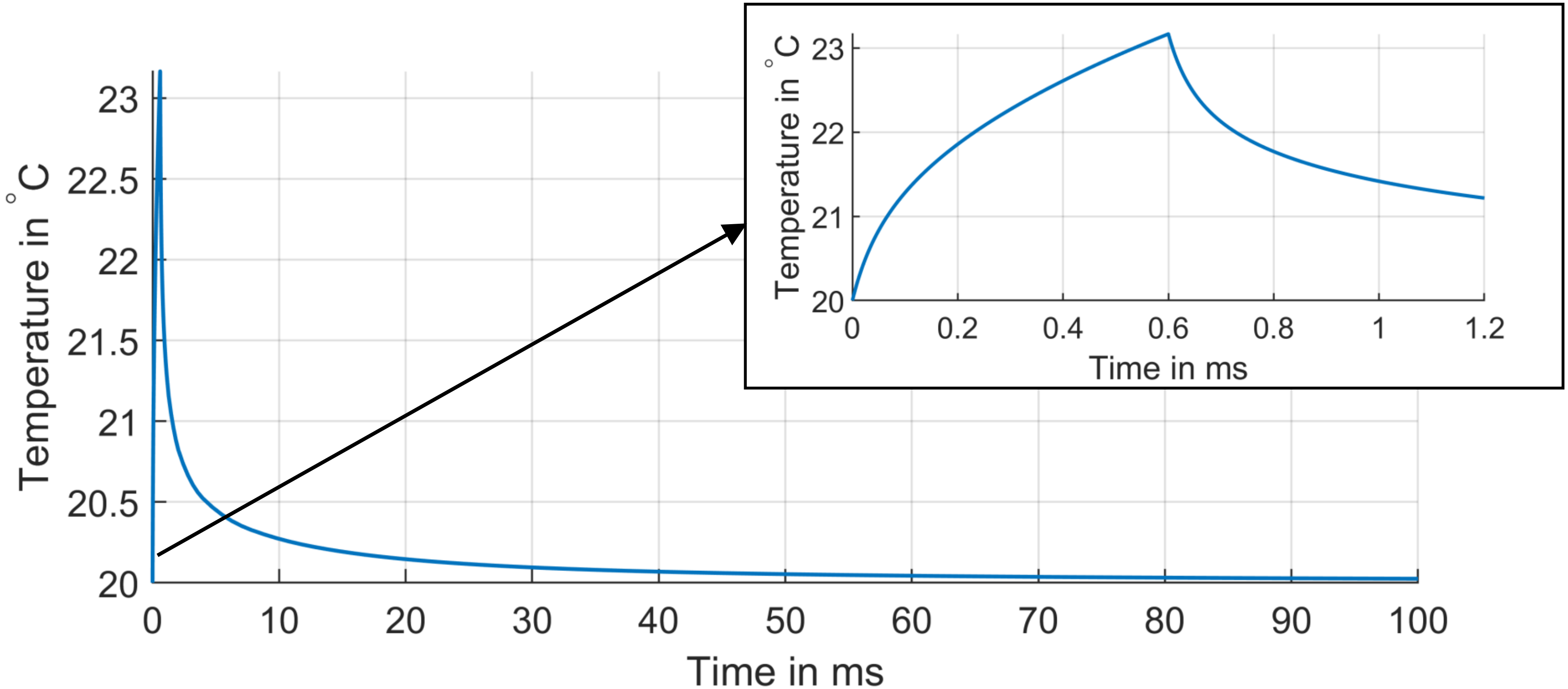
- Transient heating for single pulse



- source=top
- width=0.6 mm
- P=15 W/m
- t=0…1.2 ms
- peak temperature=23.39 ℃

Bunch Train Simulations

- Transient heating for single pulse



P=15 W/m source=top width=0.6 mm

Bunch Train Simulations

- Estimation for multiple pulses
  - Short hold time
    - Very small time step (<0.1 ms)
  - Long heating time for whole system (~1000 s)
    - Extremely long simulation
  - Estimation of peak temperature
    - Constant current and pulsed beam have same steady state
    - In the steady state, single pulse only causes local temp. increase
    - Single pulse does not affect radiation at outer surface
    - Superposition of steady state temperature with temperature increase caused by single pulse

Bunch Train Simulations

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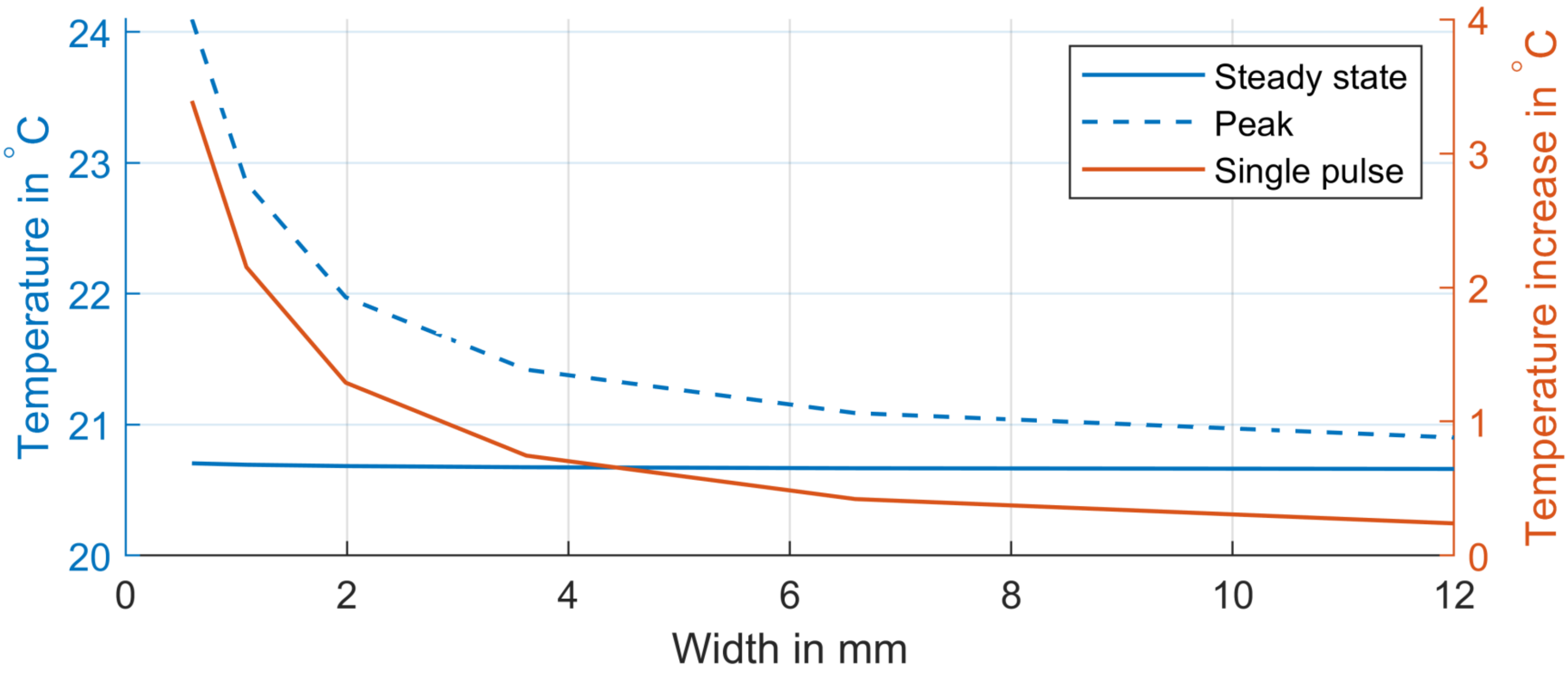
- Peak temperature estimation for isothermal boundary



P=15 W/m boundary=isothermal source=top

Bunch Train Simulations

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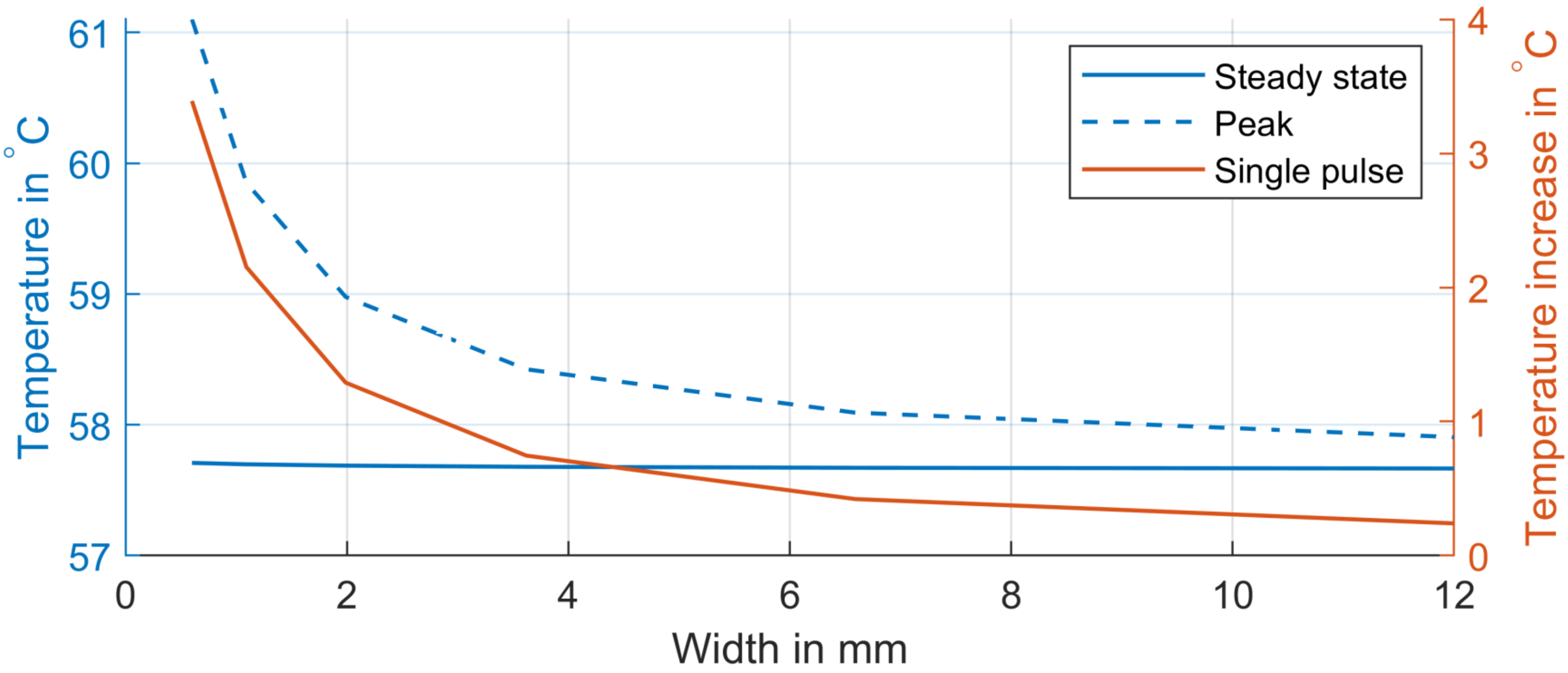
- Peak temperature estimation for radiation boundary



P=15 W/m   boundary=radiation   source=top   emissivity=0.1

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Summary & Conclusion

- Single pulse loss causes very slight temperature increase (<4 ℃)
- Temperature peaks decay fully between consecutive pulses
- Extremely small effect of single pulses on the radiating boundary
- Estimation of the full bunch train peak temperatures by superposition:
  - No cooling, ε=0.1, 15 W/m: 61.2 ℃
  - No cooling, dark paint, 15 W/m : <35 ℃
  - Cooling outer pipe to ambient temperature: 24.2 ℃