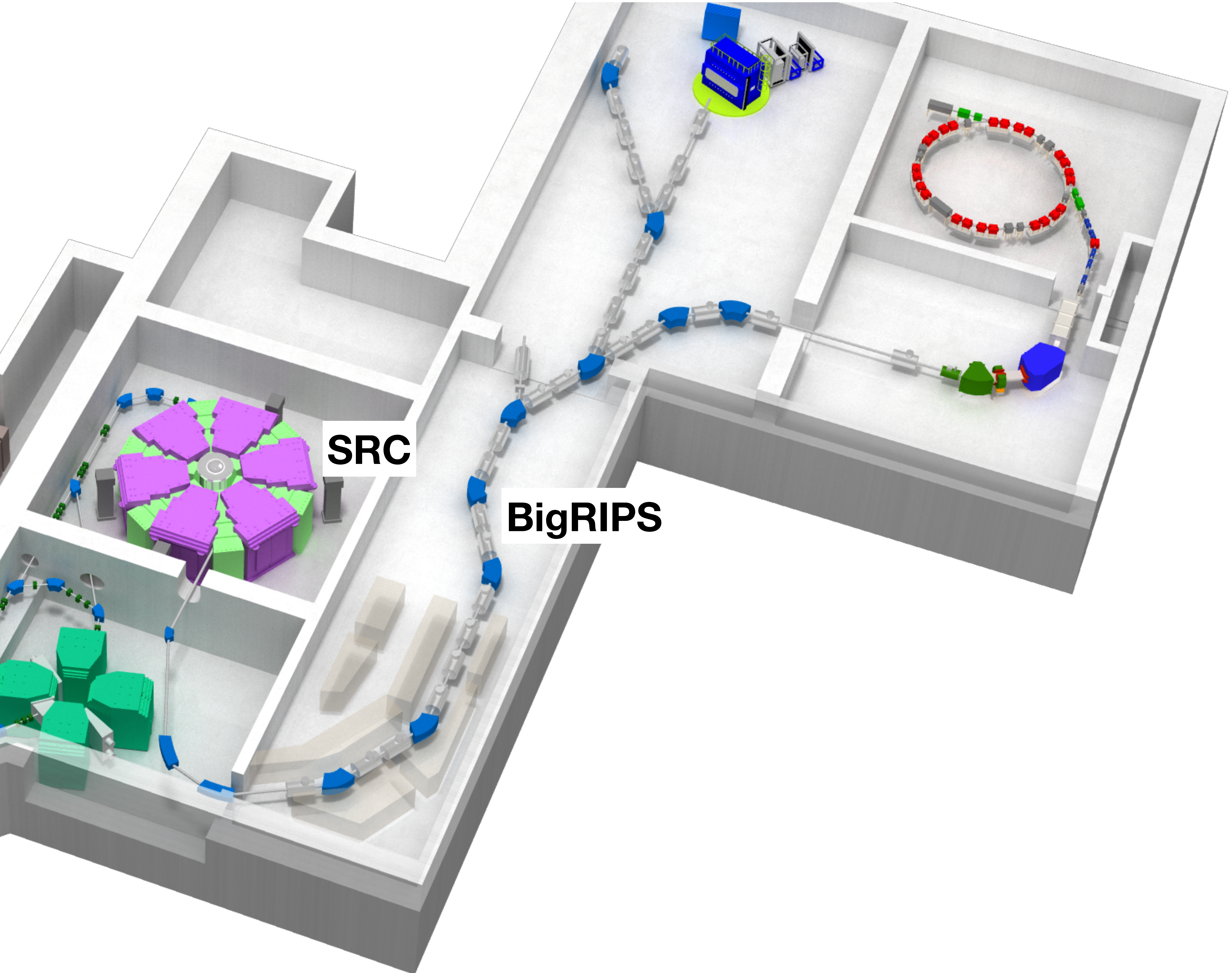
The High-Power Beam Dump System for the BigRIPS separator

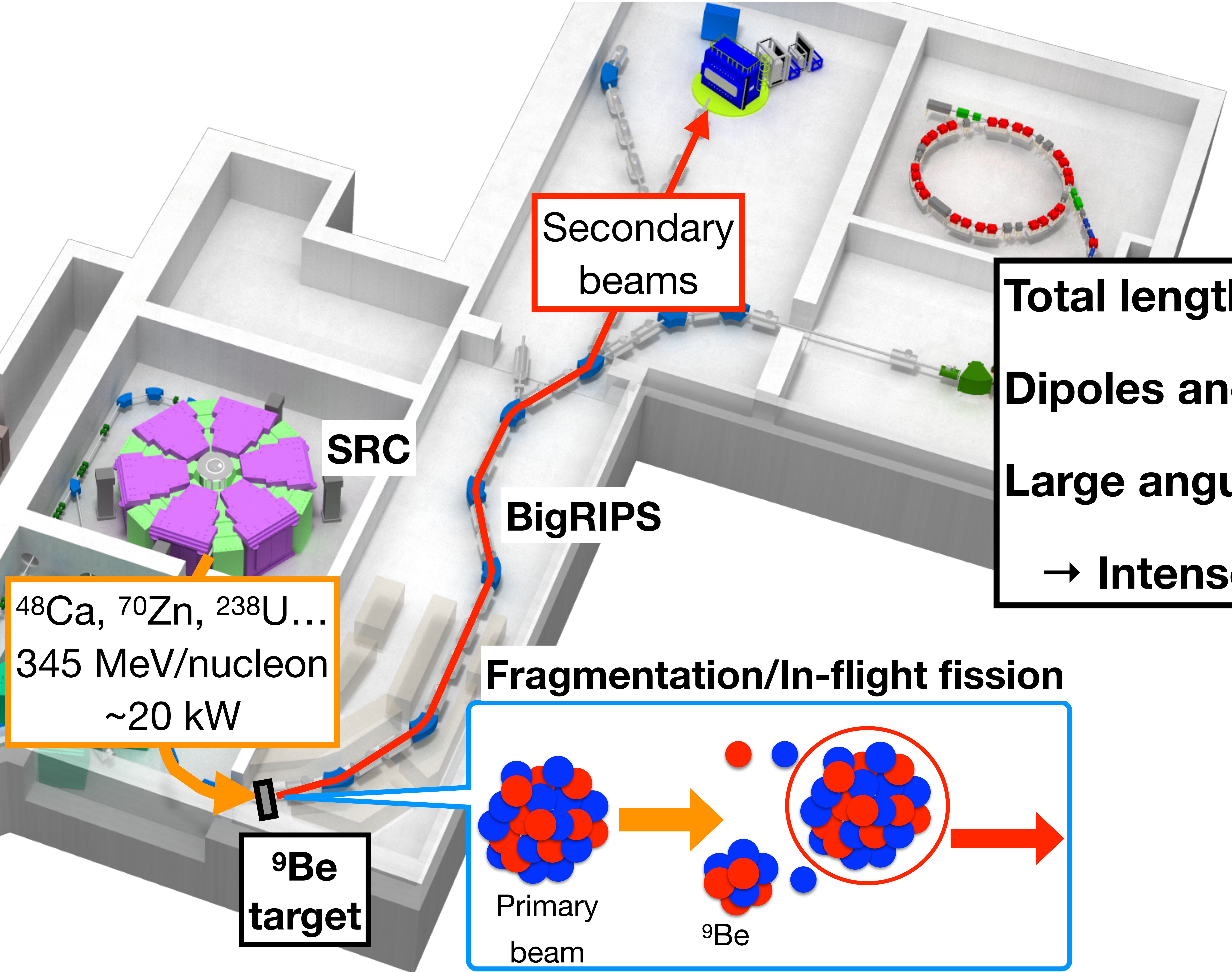
Yasuhiro Togano for the BigRIPS team

RIKEN Nishina Center

The BigRIPS Separator: Produce & Separate Exotic Nuclei



The BigRIPS Separator: Produce & Separate Exotic Nuclei



Total length: ~80 m

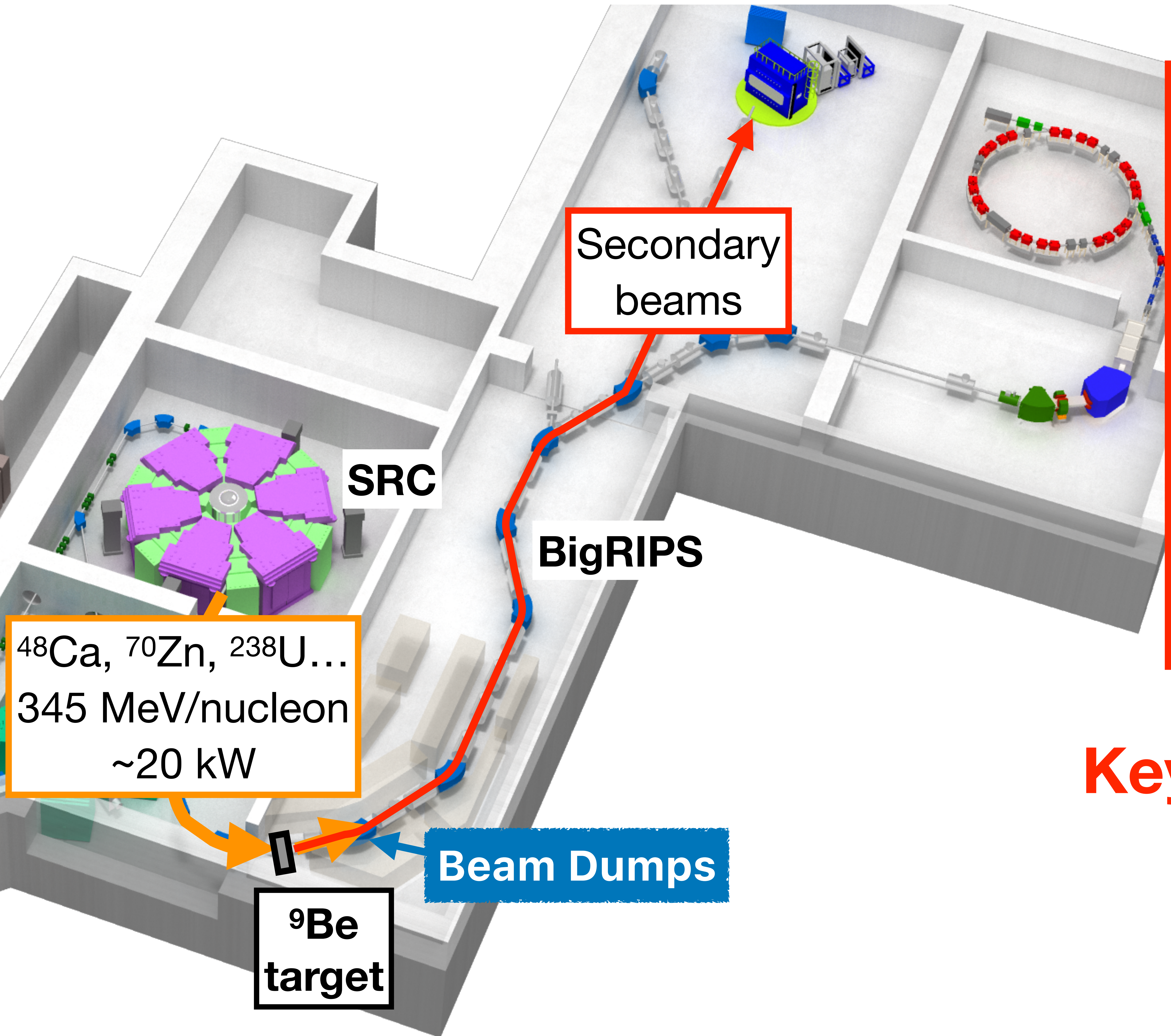
Dipoles and superconducting Q magnets

Large angular & momentum acceptance

→ Intense secondary beams

Fragmentation/In-flight fission

Requirements for BigRIPS Beam Dumps



^{70}Zn @ 345 MeV/nucleon

(Almost) DC beam

Range in Cu: 8.3 mm

Small beam spot: $\sigma \leq 5$ mm

Beam power : ~20 kW

→ heat flux: > 100 MW/m^2

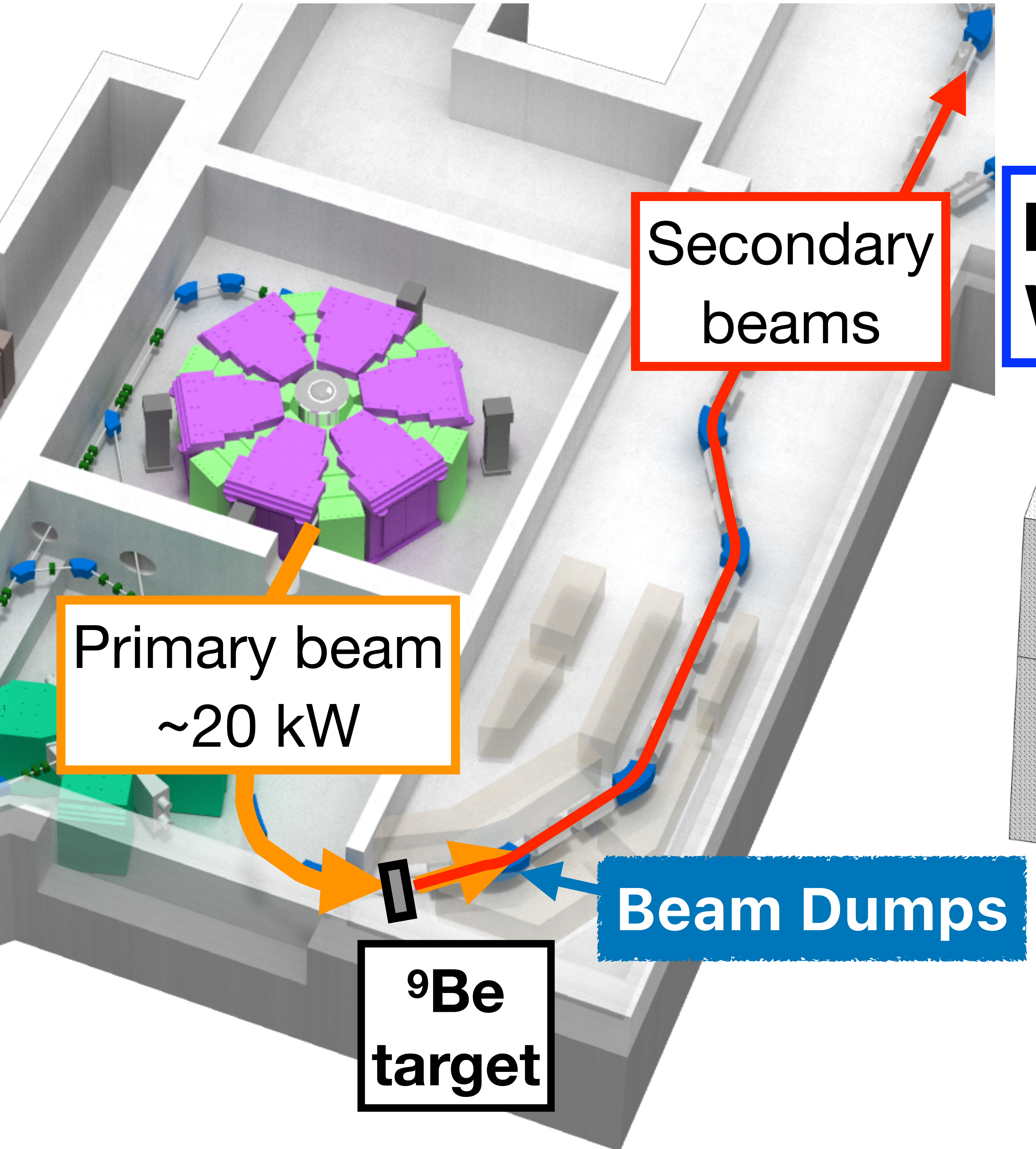
→ heat density: >10 GW/m^3

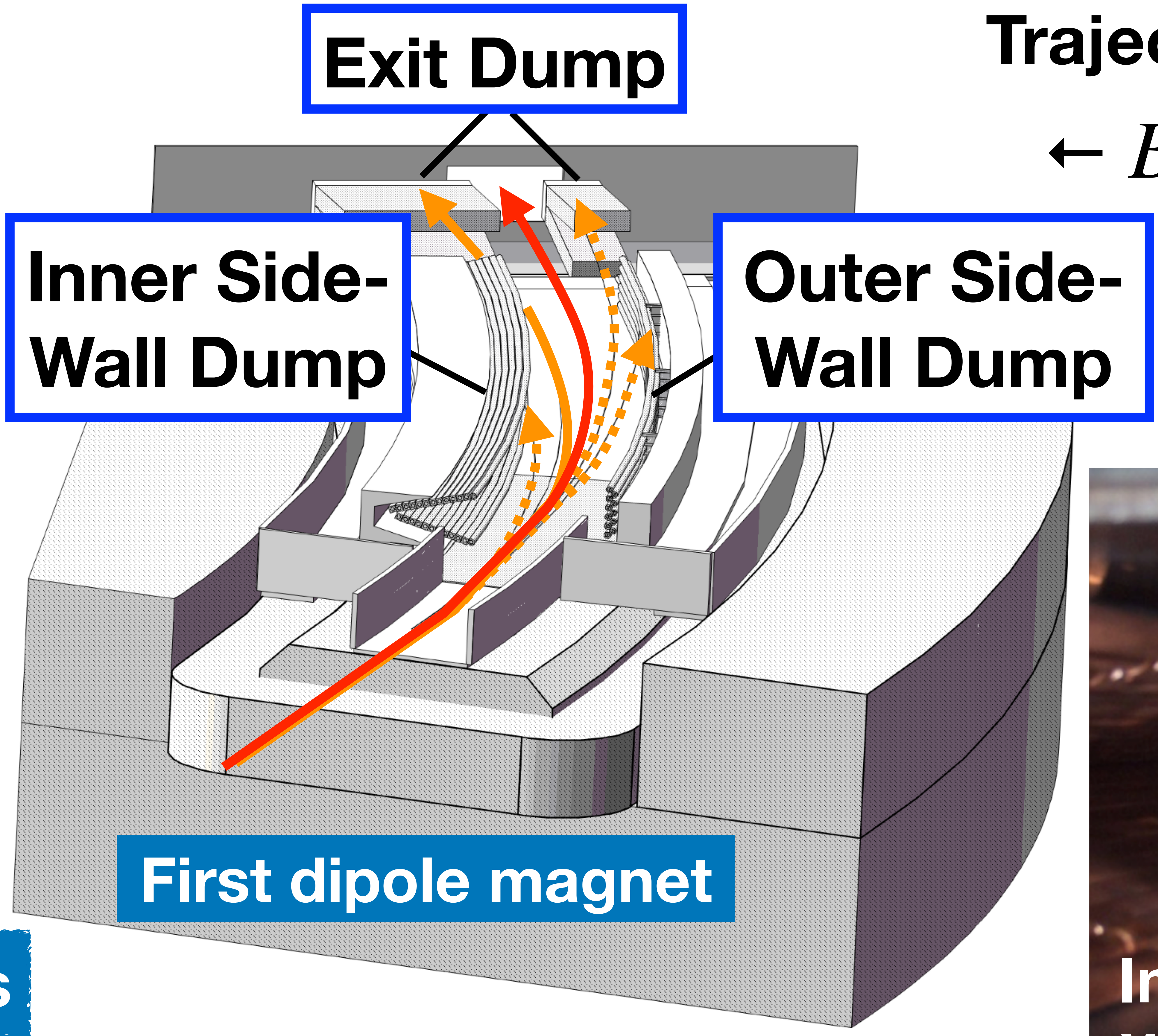
Key for beam dumps =

Removal of localized heat

Water Cooled Beam Dumps for BigRIPS

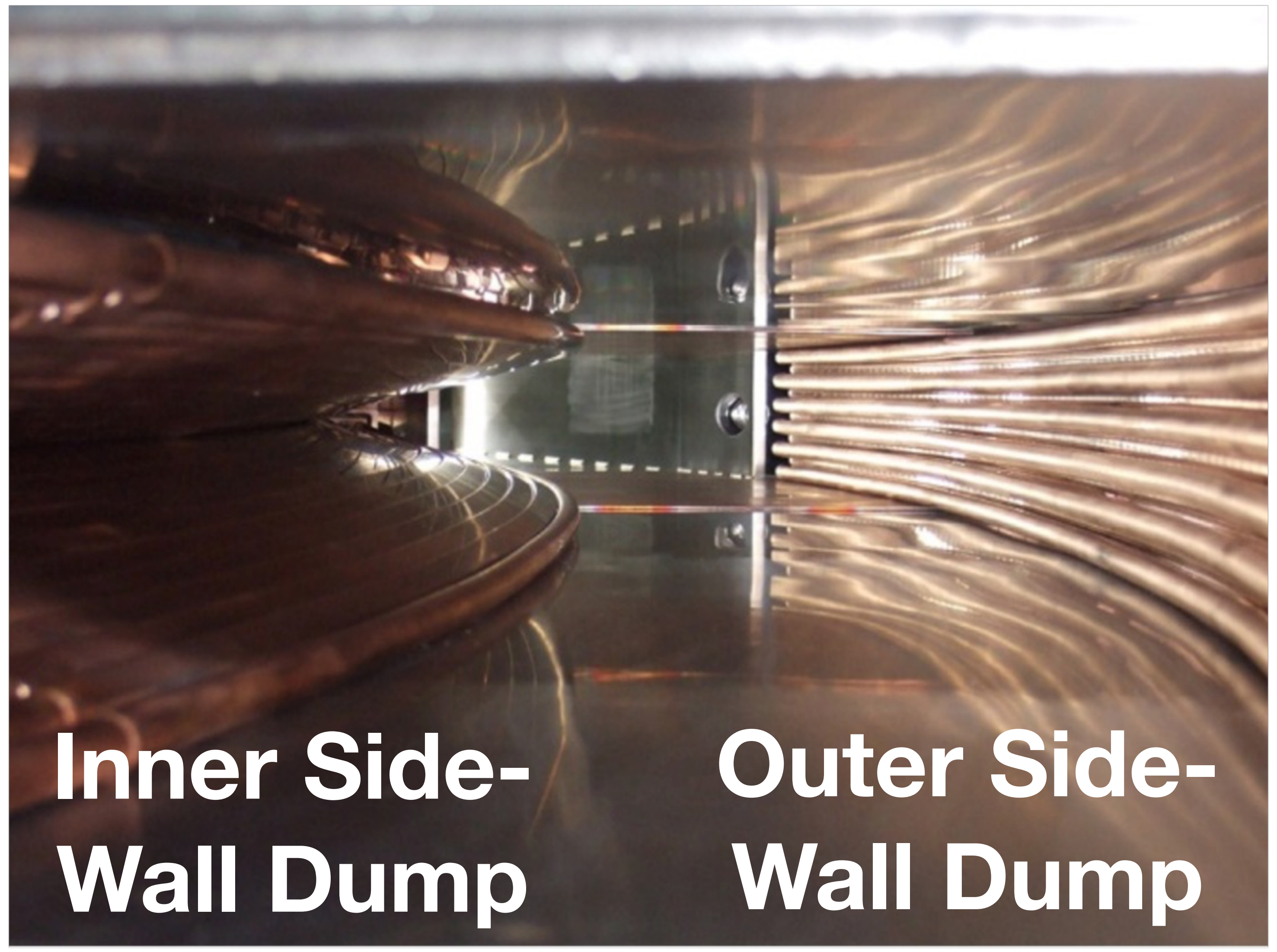
3 different beam dumps around the first dipole magnet





Trajectory of primary beam

← $B\rho$ of secondary beam

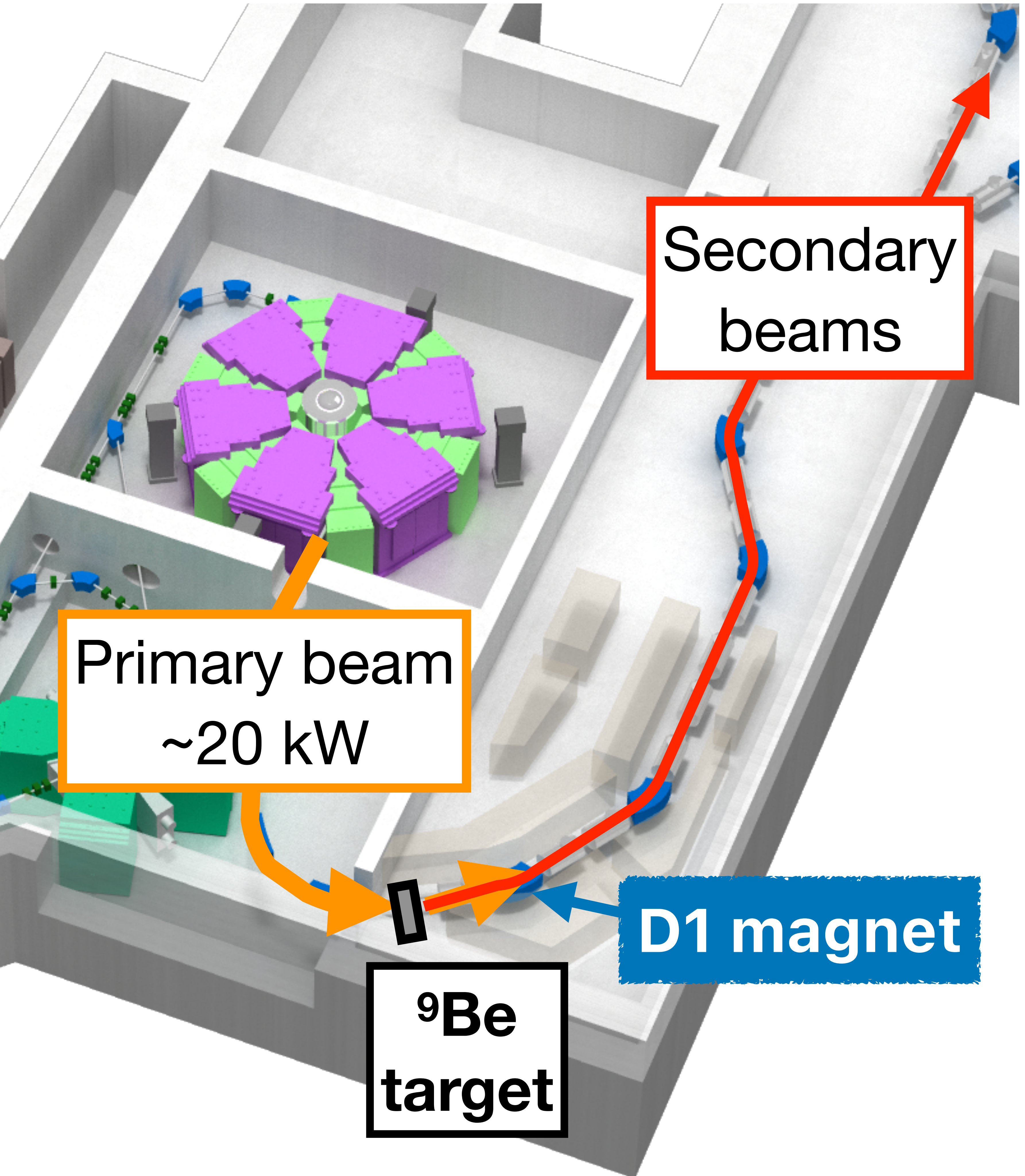


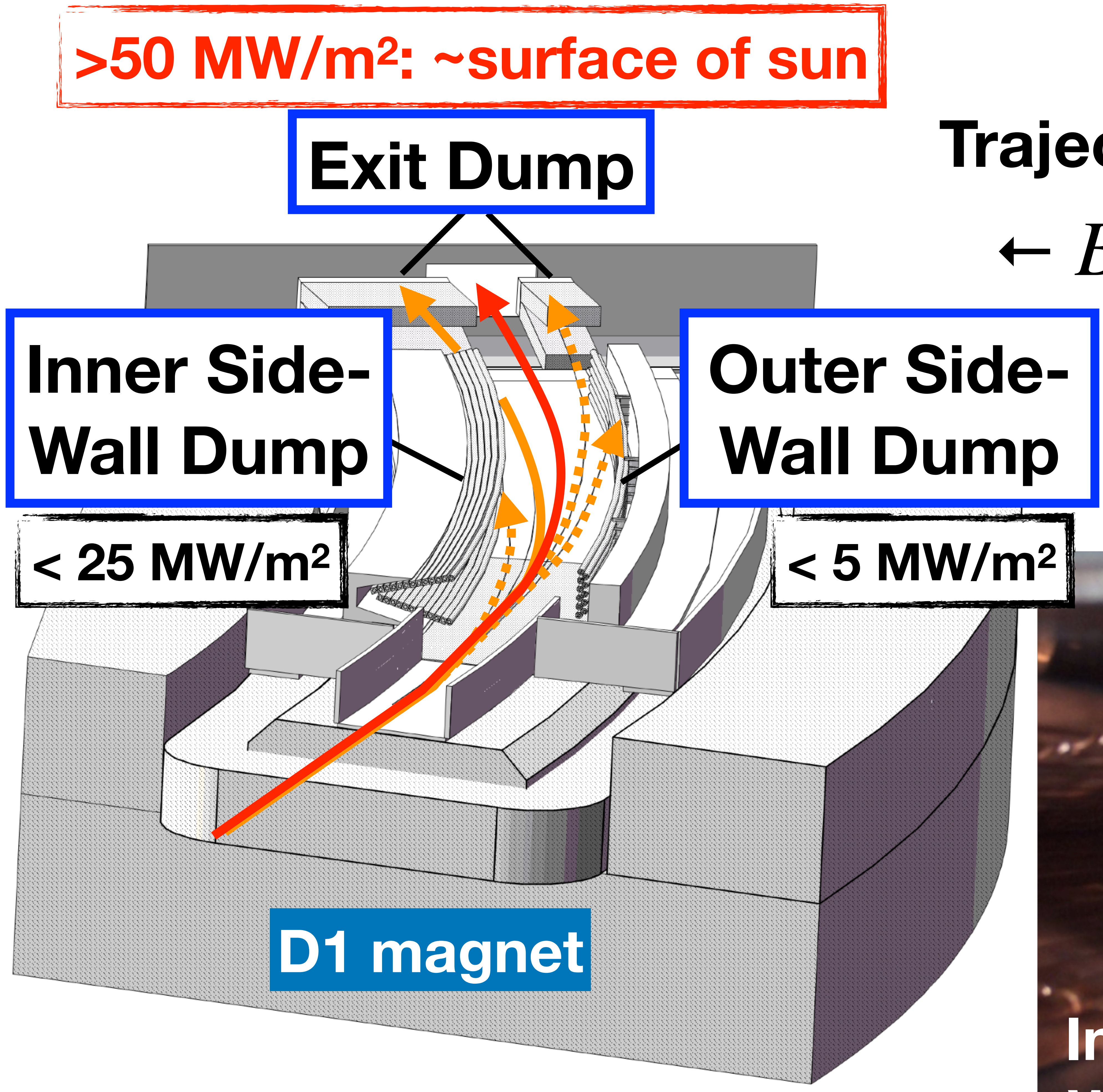
Water Cooled Beam Dumps for BigRIPS

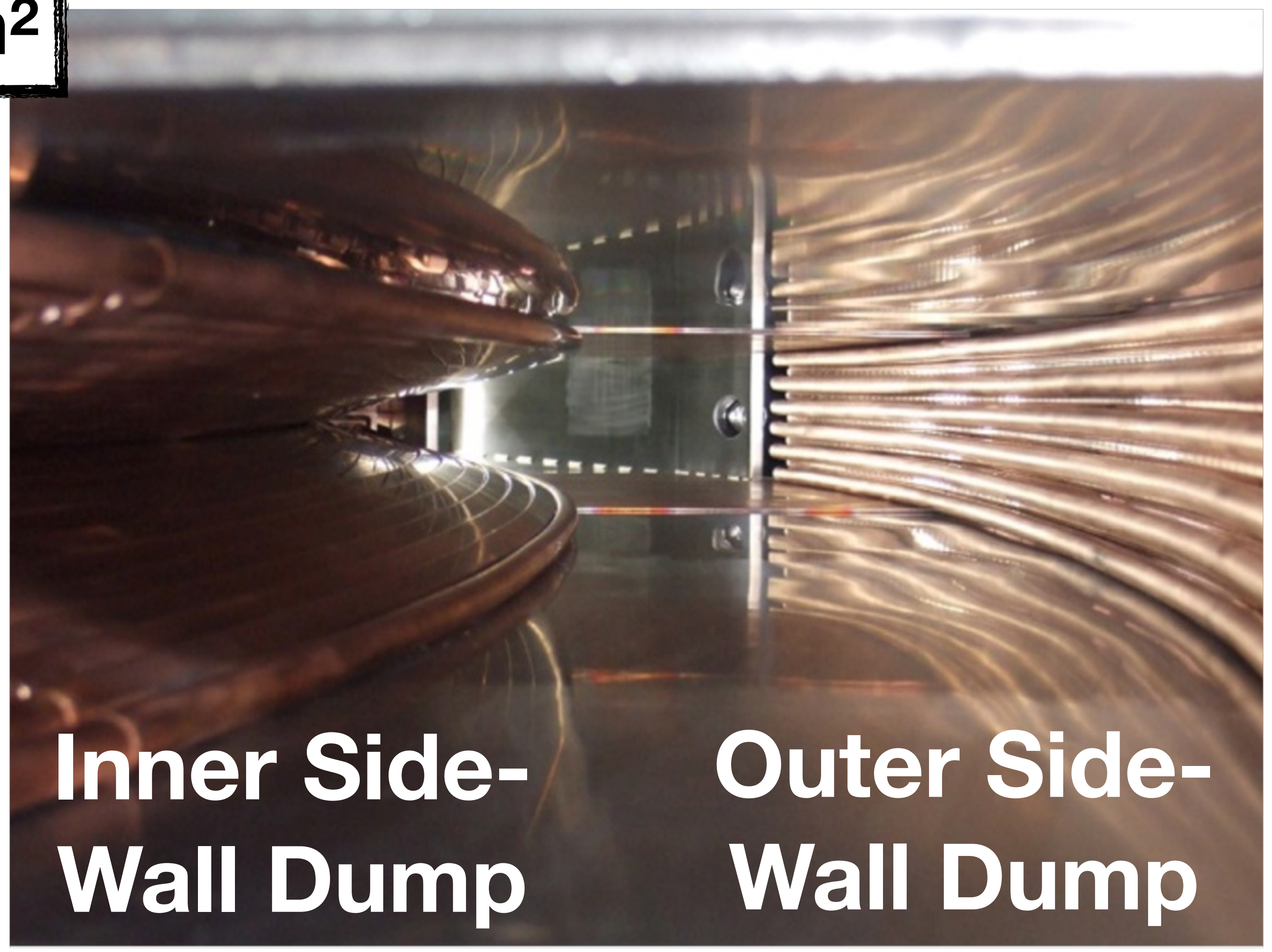
3 different beam dumps around the first dipole (D1) magnet

Trajectory of primary beam

← $B\rho$ of secondary beam







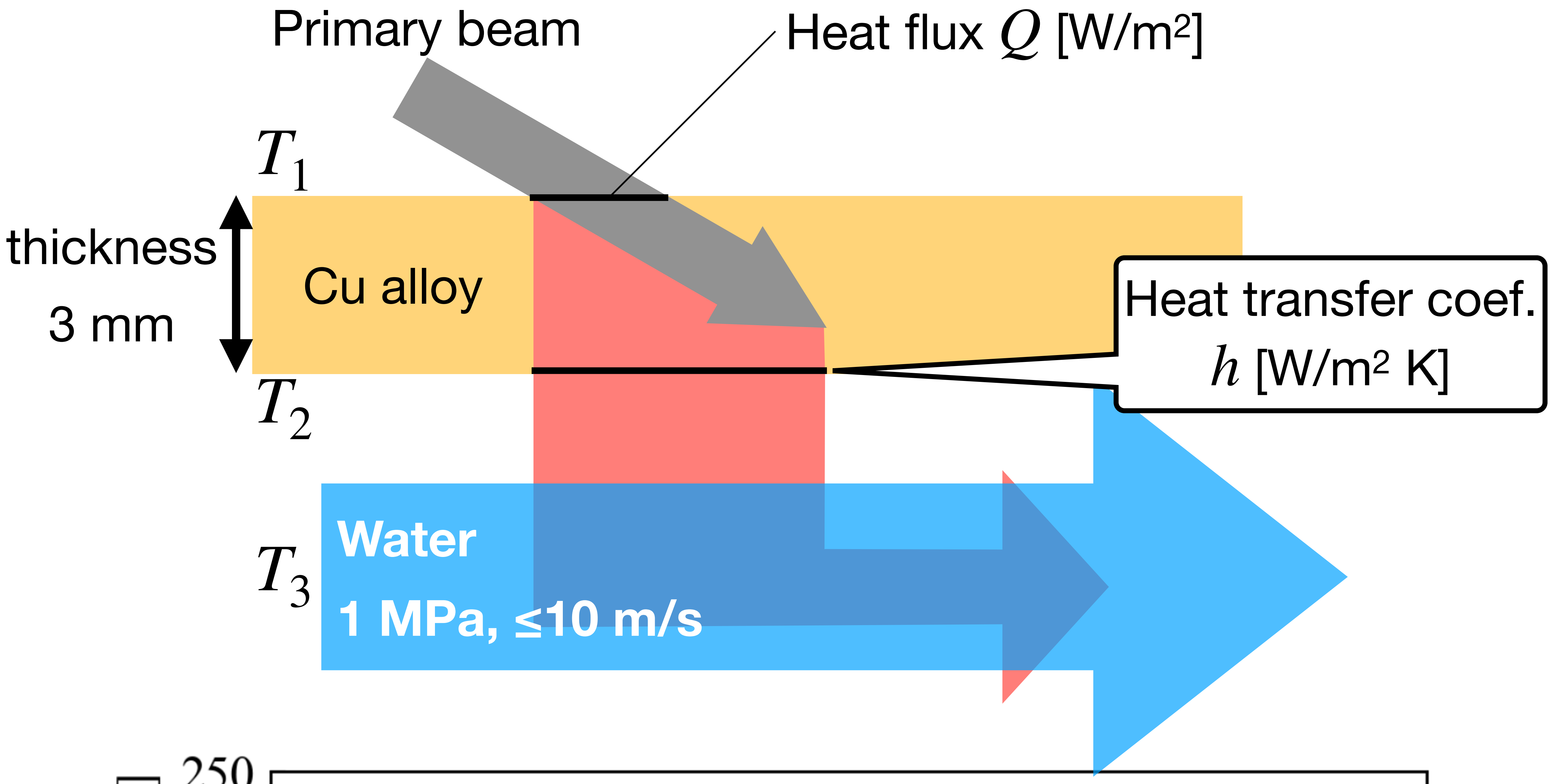
Exit Dump at Maintenance Position

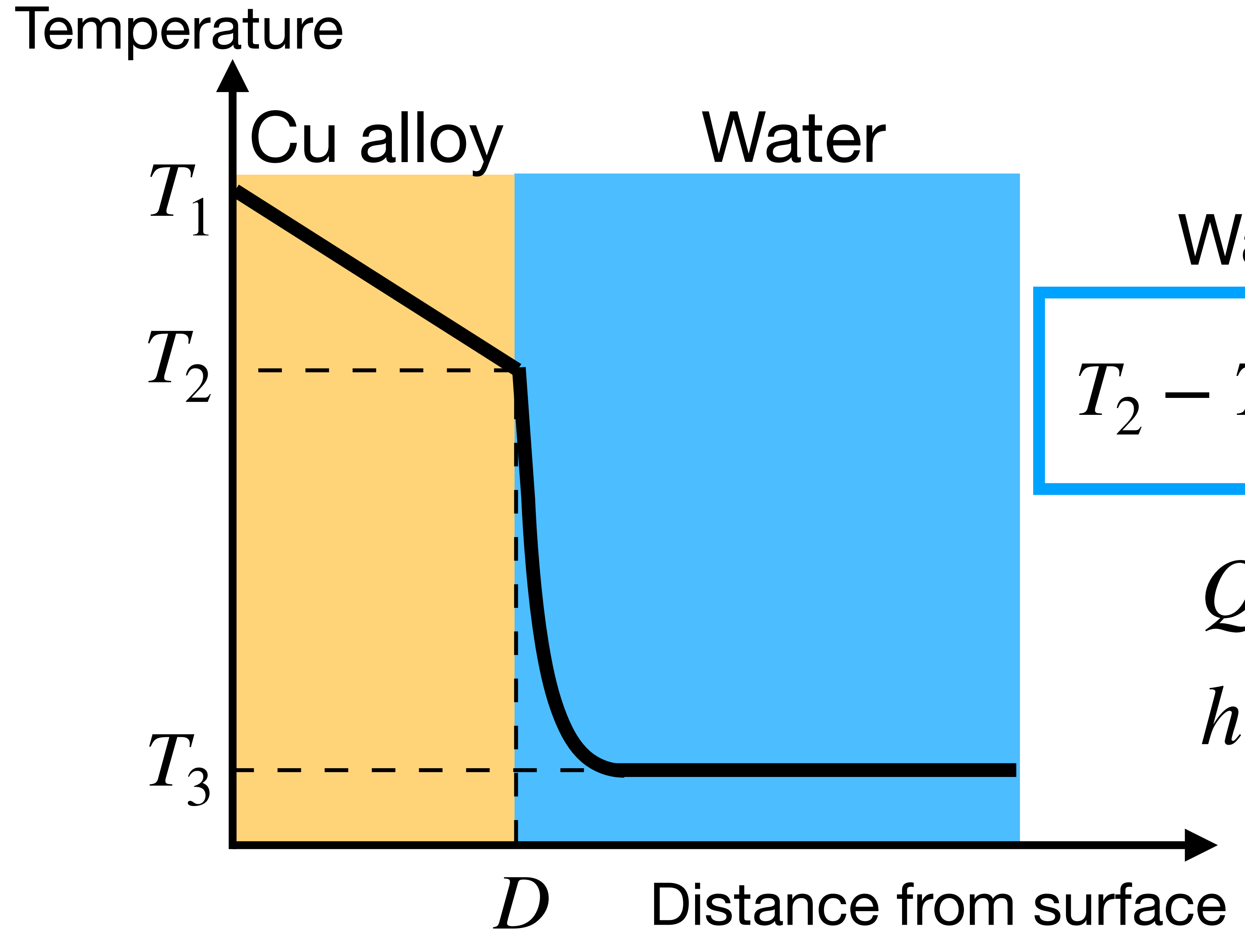
Exit Dump at Maintenance Position

CuCrZr alloy→ Radiation hardness

- **V shape: enlarge beam spot on the surface**
- **Cooled by water in screw tubes 3-mm below surface**
  - **Screw tube: better heat transfer than flat tubes**

Cooling Localized Heat: Transfer to Water



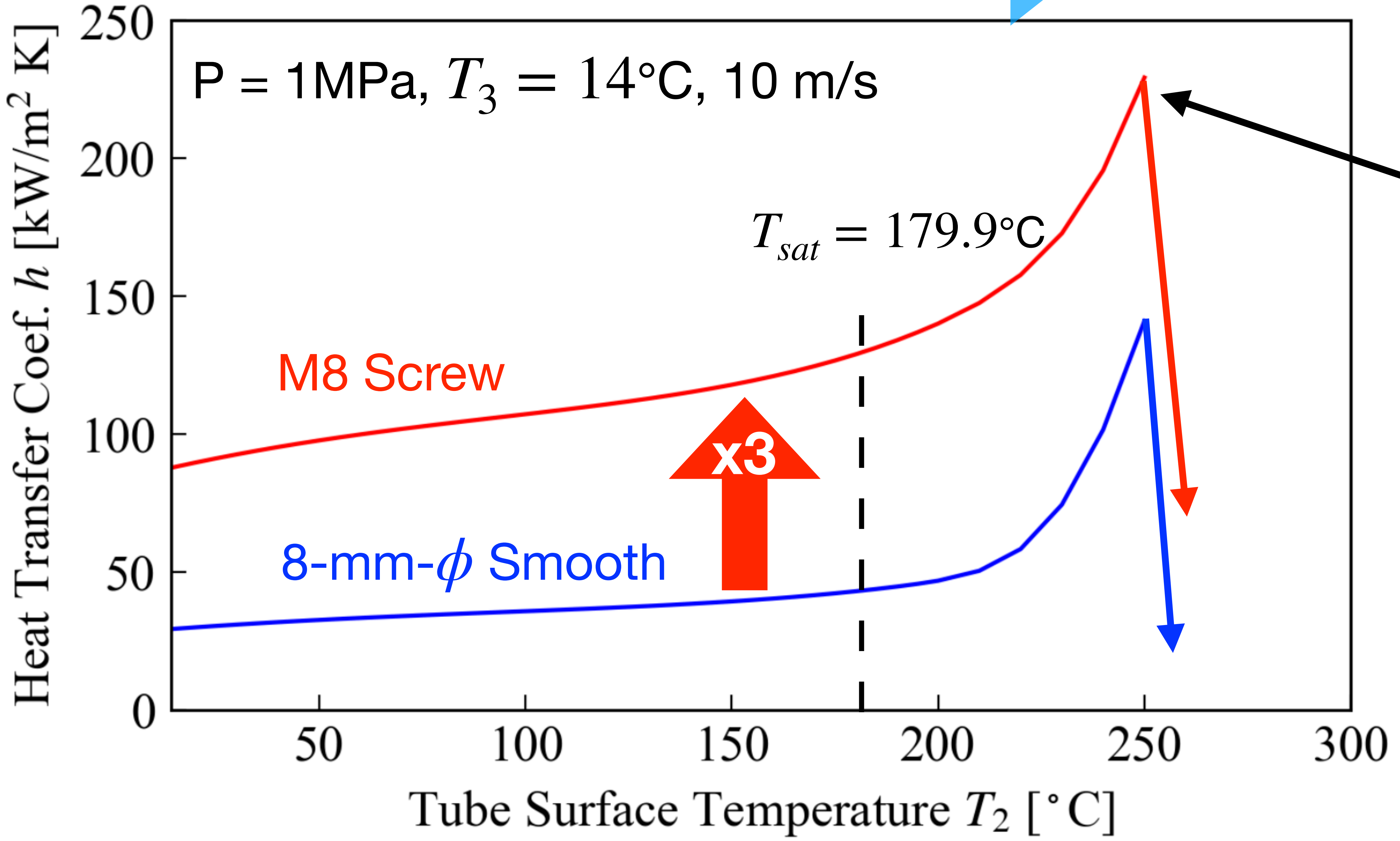


Water

$$\boxed{T_2 - T_3 = \frac{Q}{h}}$$

Q : Beam condition

h : Water condition



Critical temperature: $T_C \simeq 250$°C

Water tube: covered with vapor ← vigorous boiling

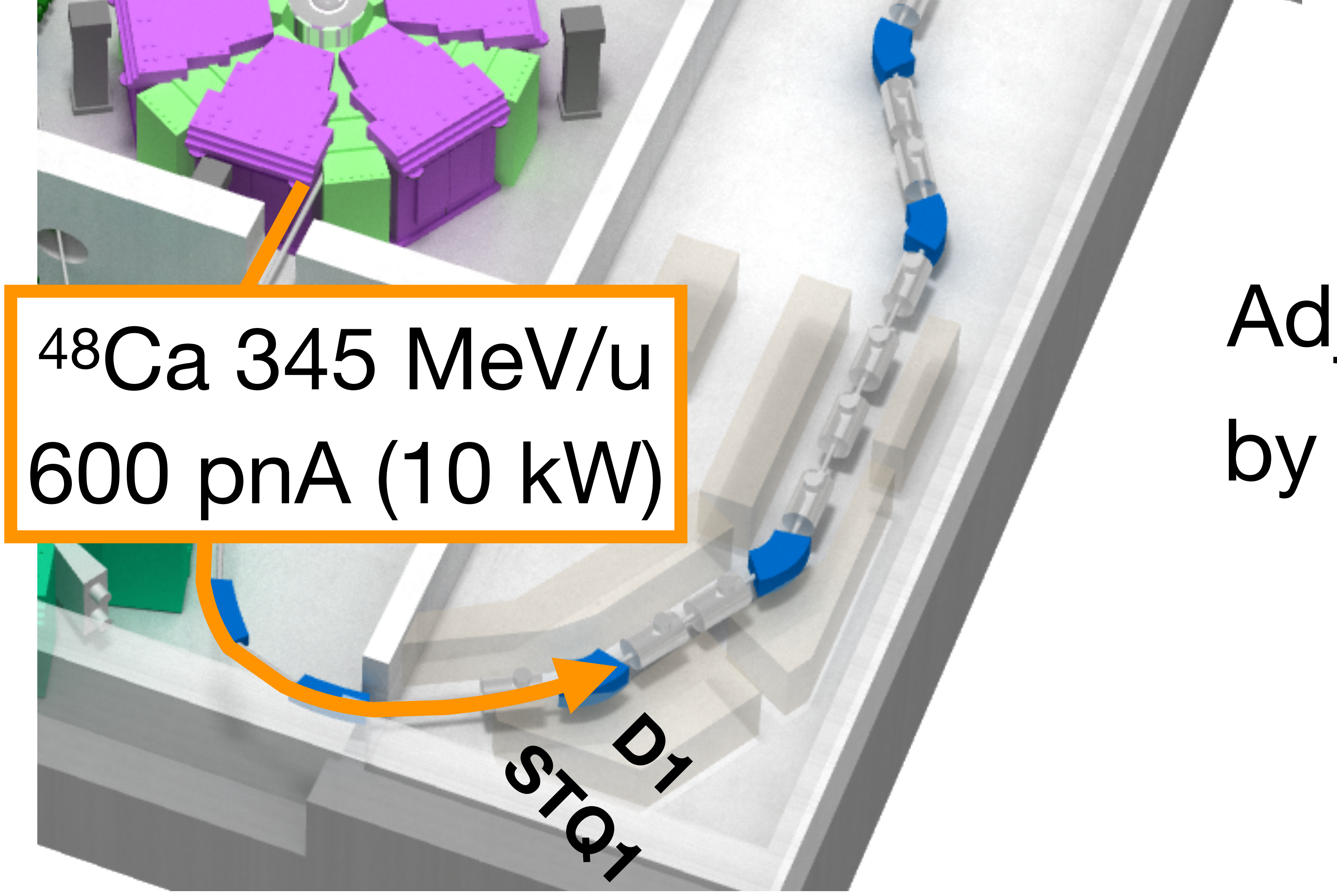
→ Much reduced heat transfer rate

$T_2 > T_C$ (250°C): Dump will be damaged

J. Boscary et al., Fusion Eng. Des. 43, 147 (1998).

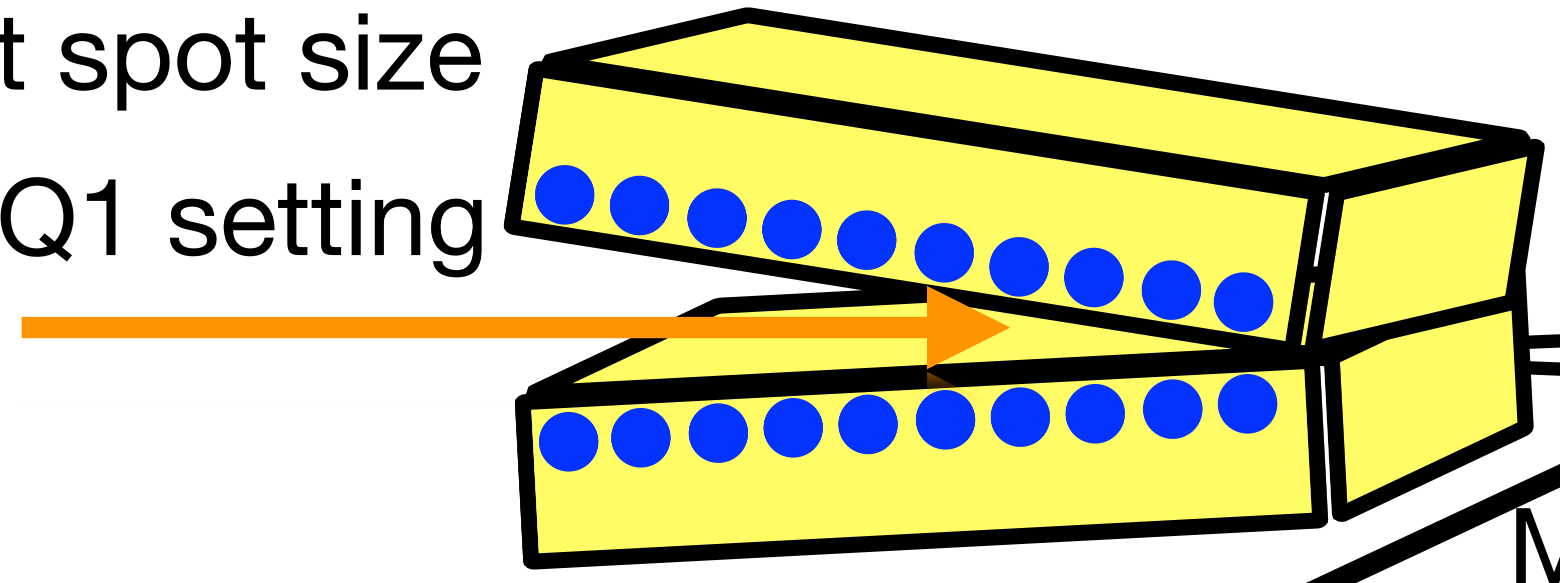
K. Masaki et al., Fusion Eng. Des. 61, 171 (2002).

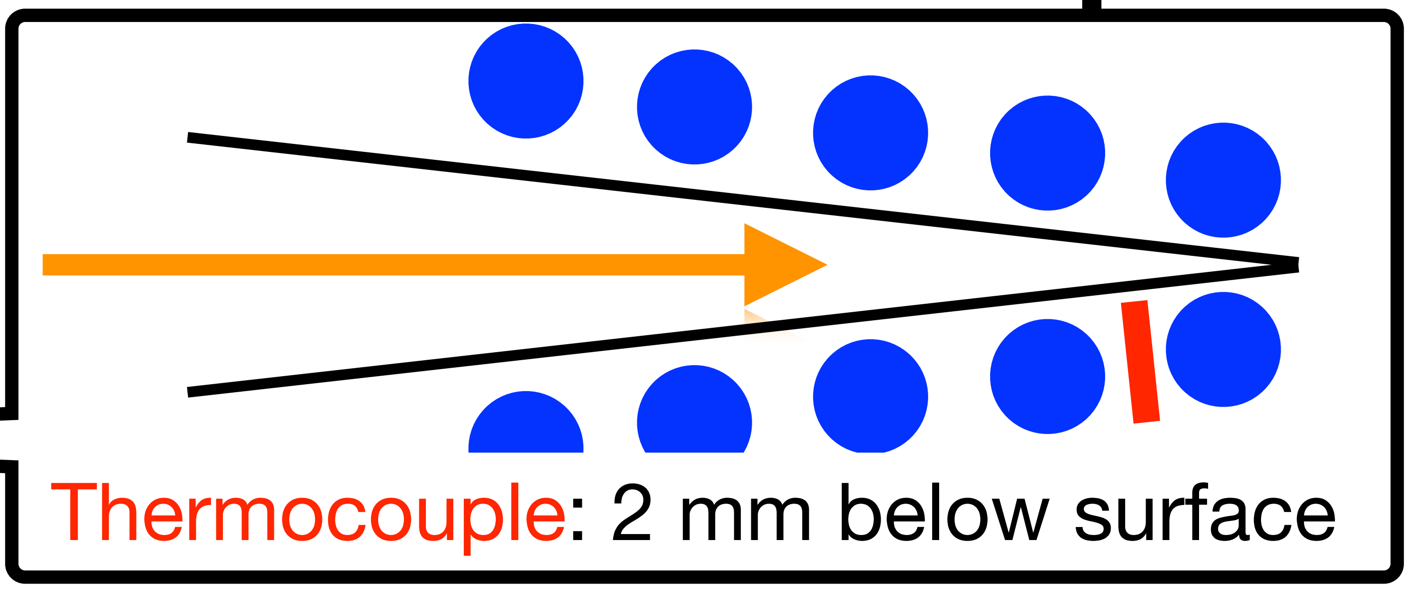
Cooling Capability of Exit Dump



Adjust spot size

by STQ1 setting

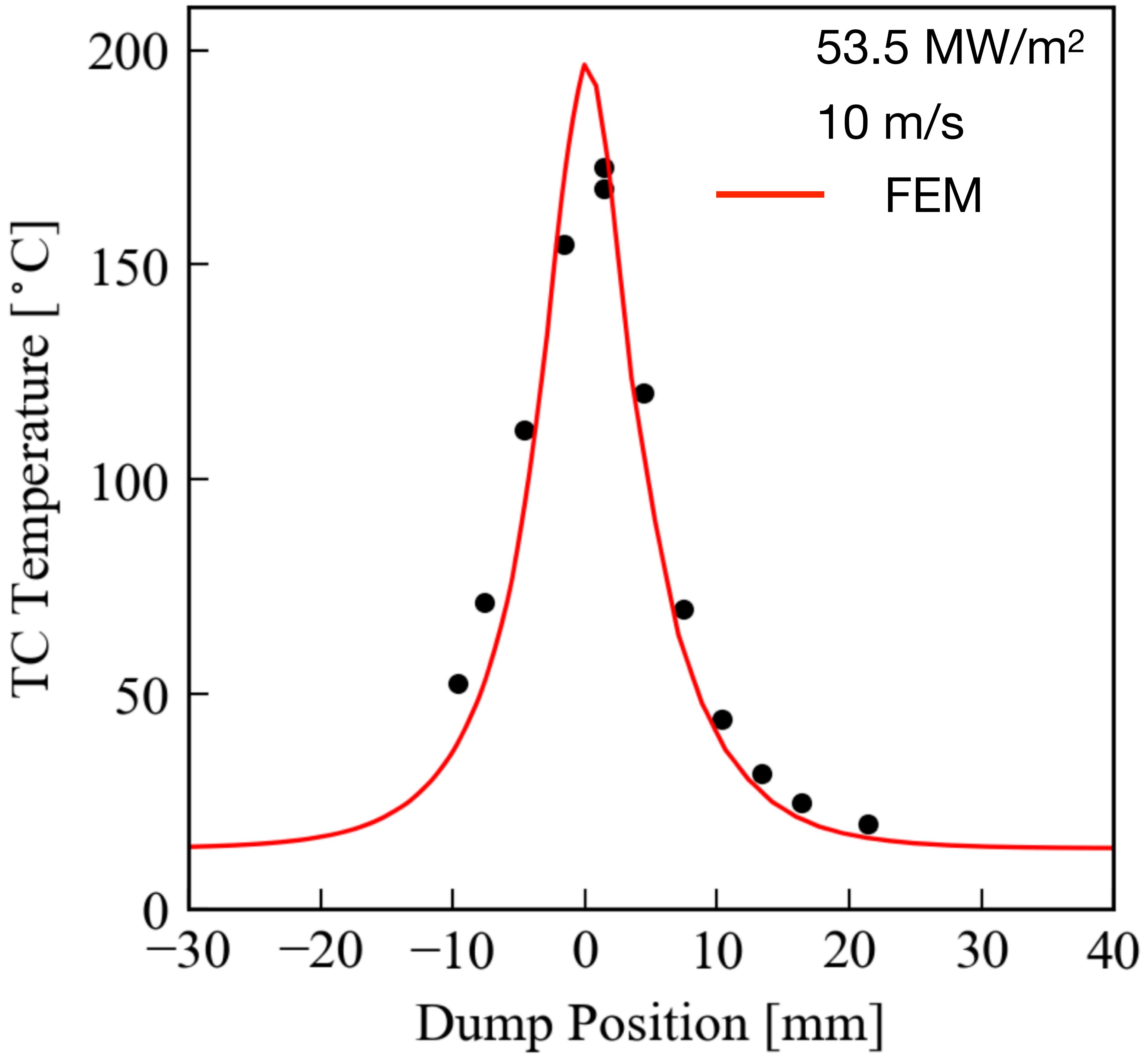


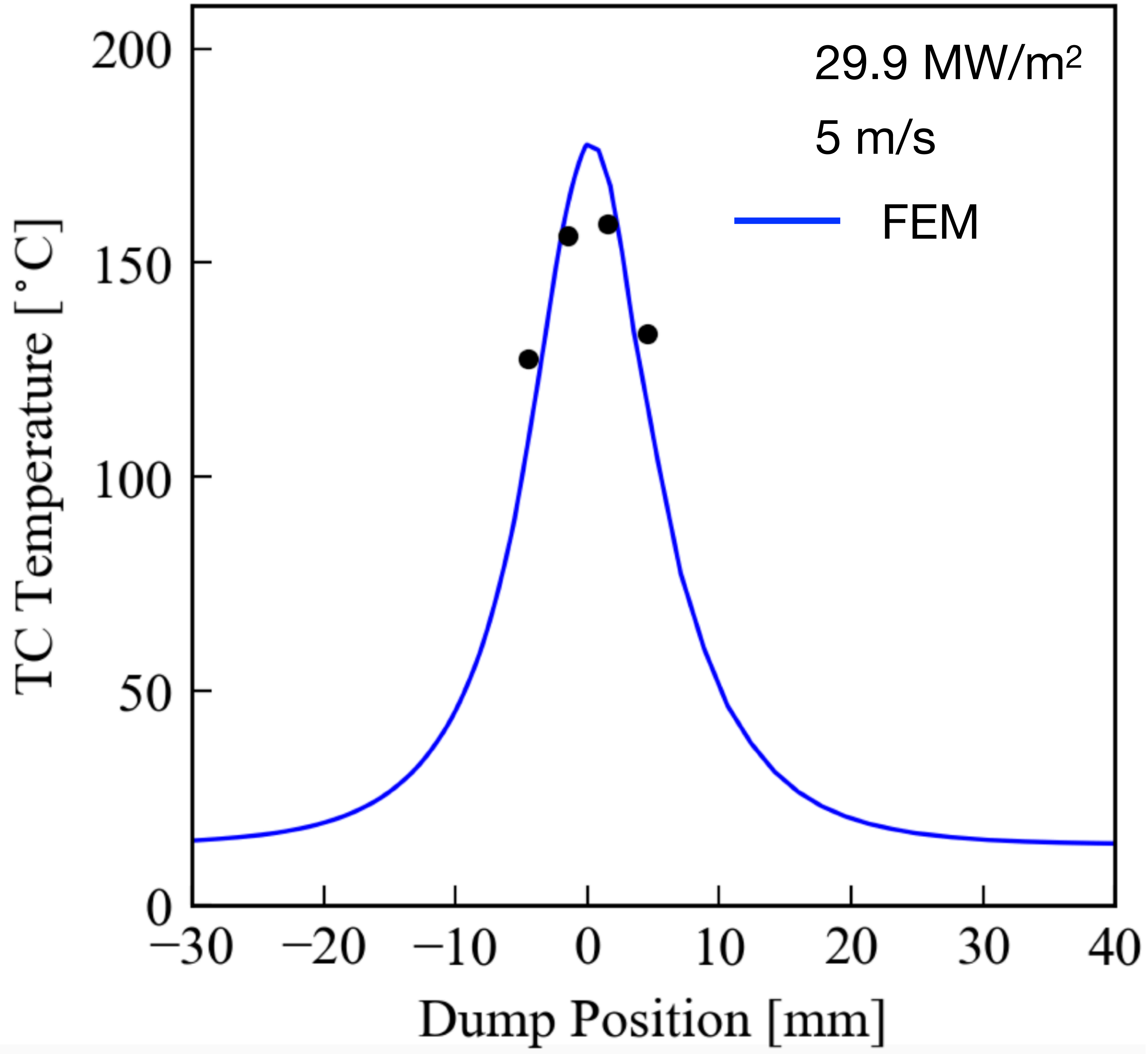


Range of ^{48}Ca = 12.8 mm

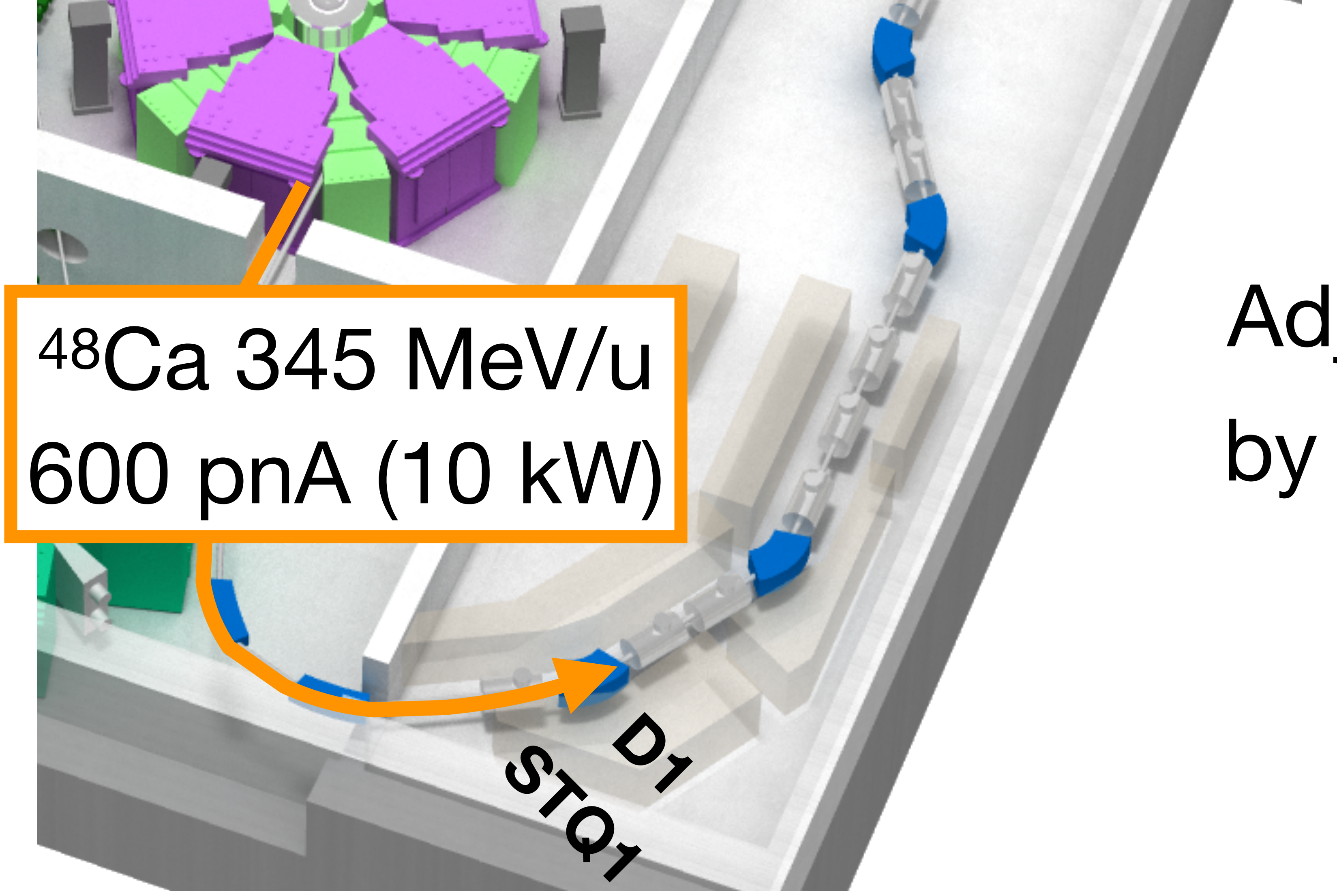
Move the dump

→ obtain T distribution





Cooling Capability of Exit Dump



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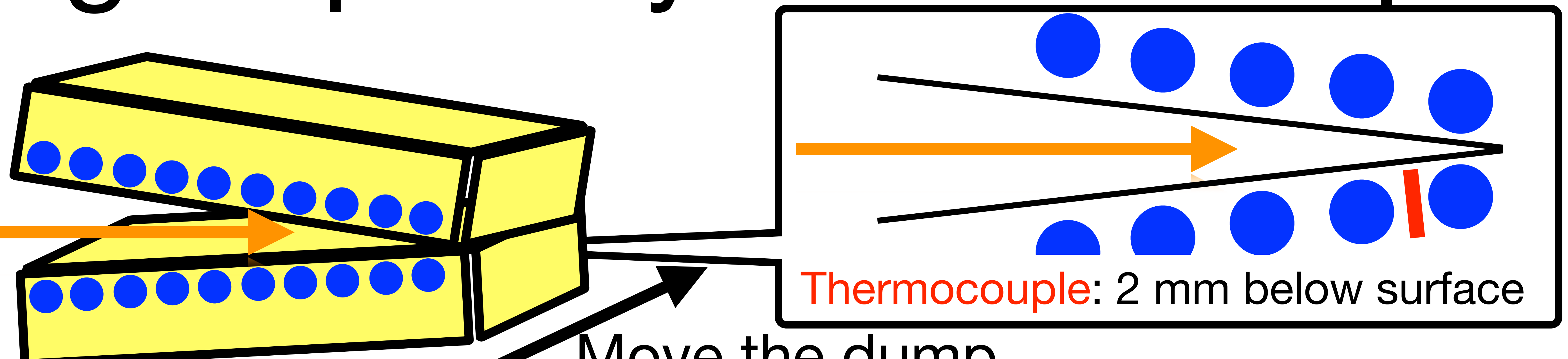

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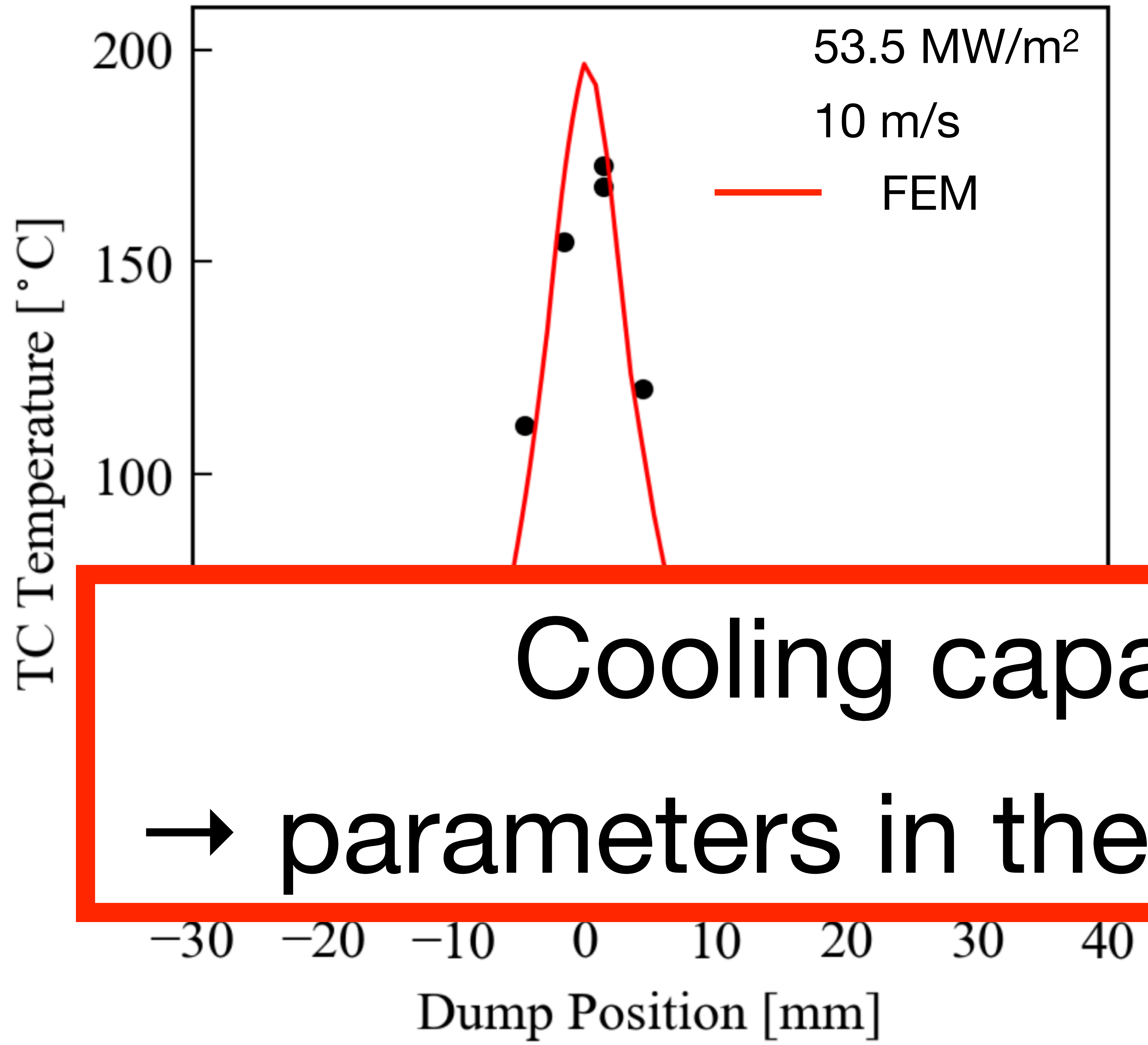
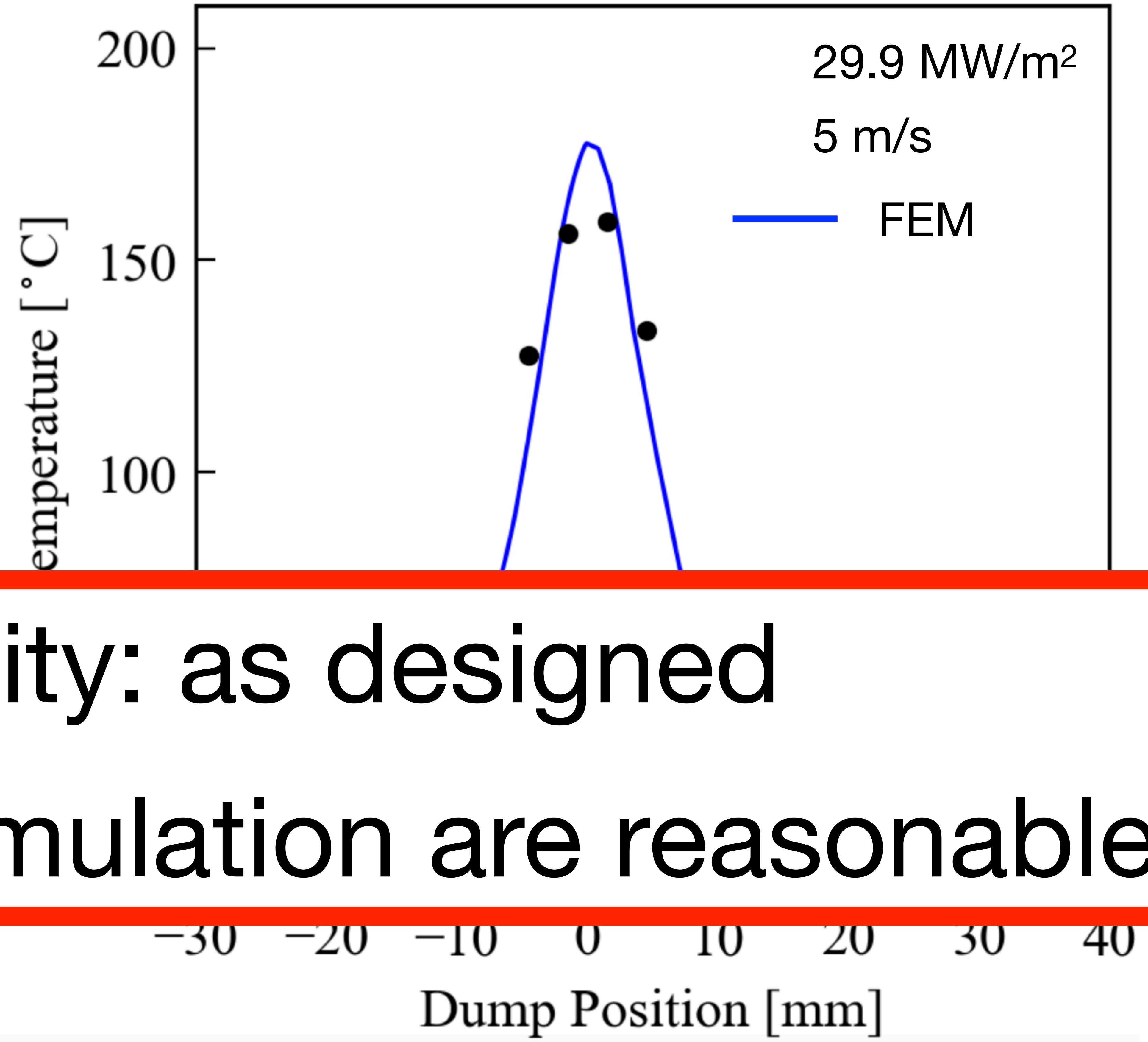


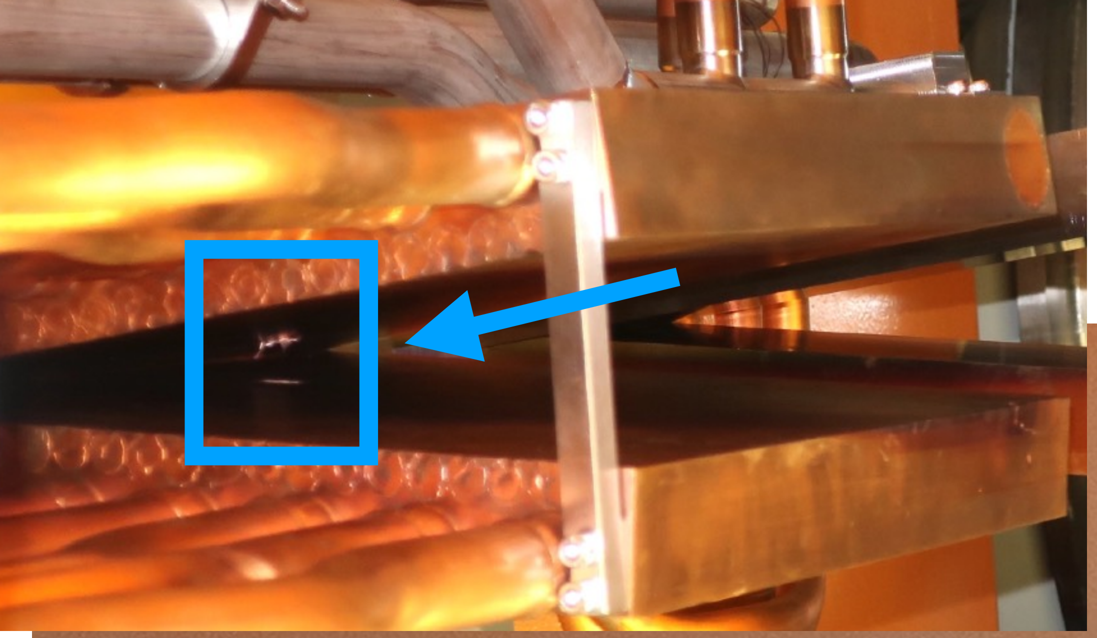


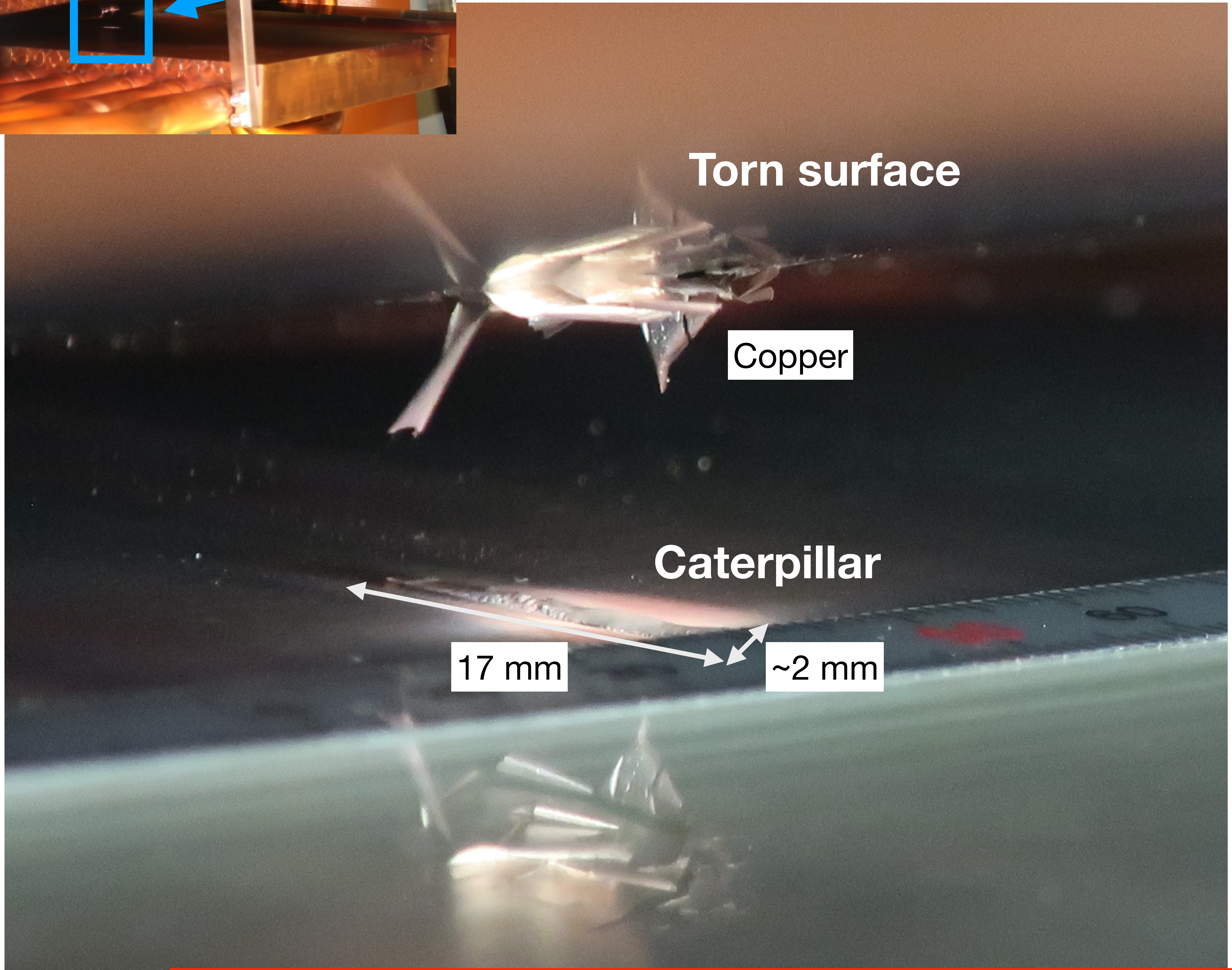
Cooling capability: as designed

→ parameters in the simulation are reasonable.

Exit Dump in May 2023

Recent Incident: Molten Mark on Dump





Not found before autumn 2022

December 2022

Direct ^{70}Zn beam for Acc. tuning

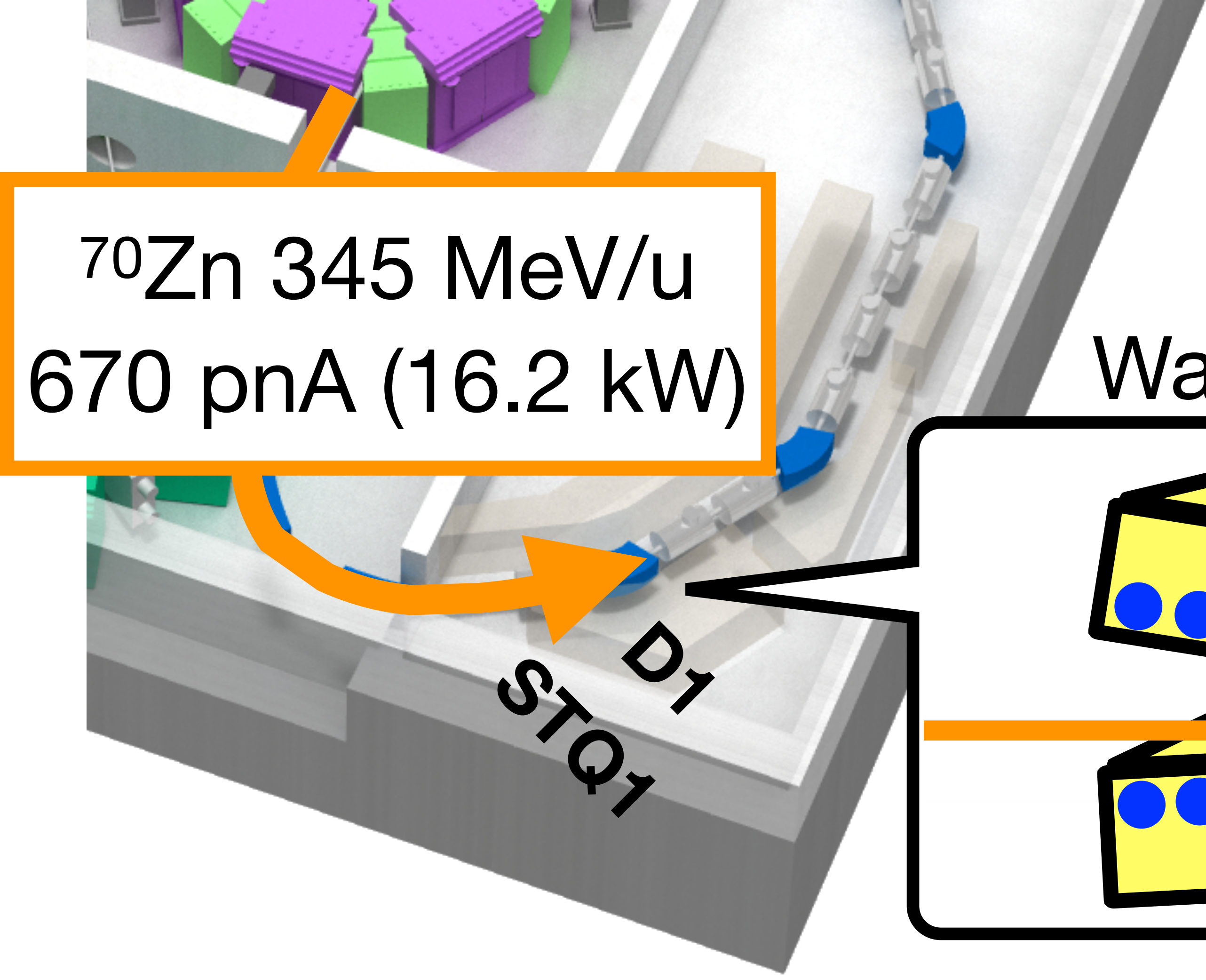
Max beam intensity = 670 pnA = 16.2 kW

Caterpillar position

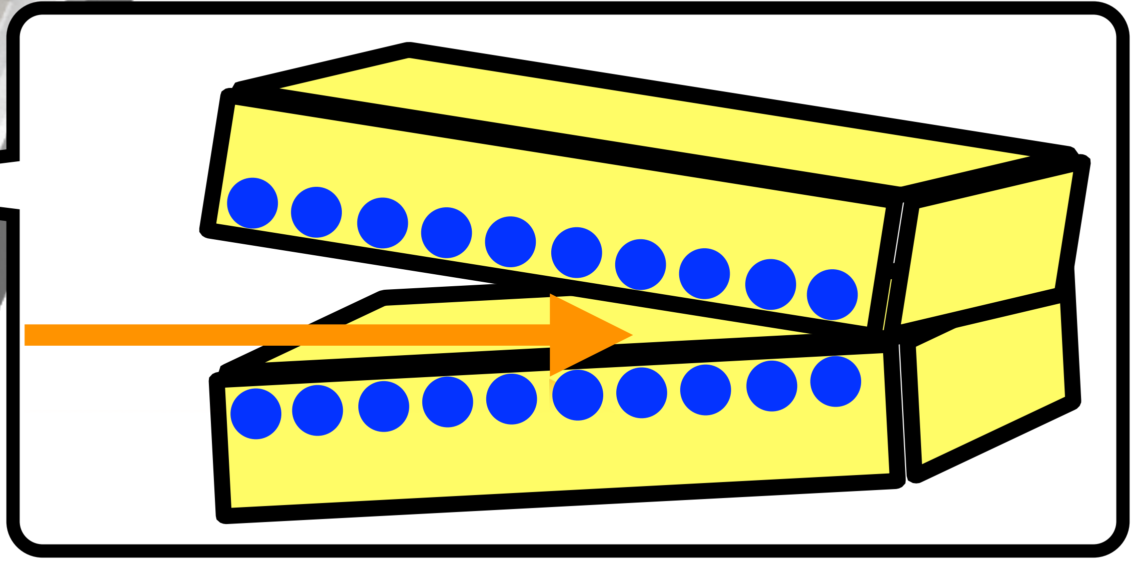
~ Position of direct ^{70}Zn beam

Thermal simulation of direct ^{70}Zn beam by finite-element method

Preliminary Thermal Simulation



Water: 1 MPa, 6 m/s

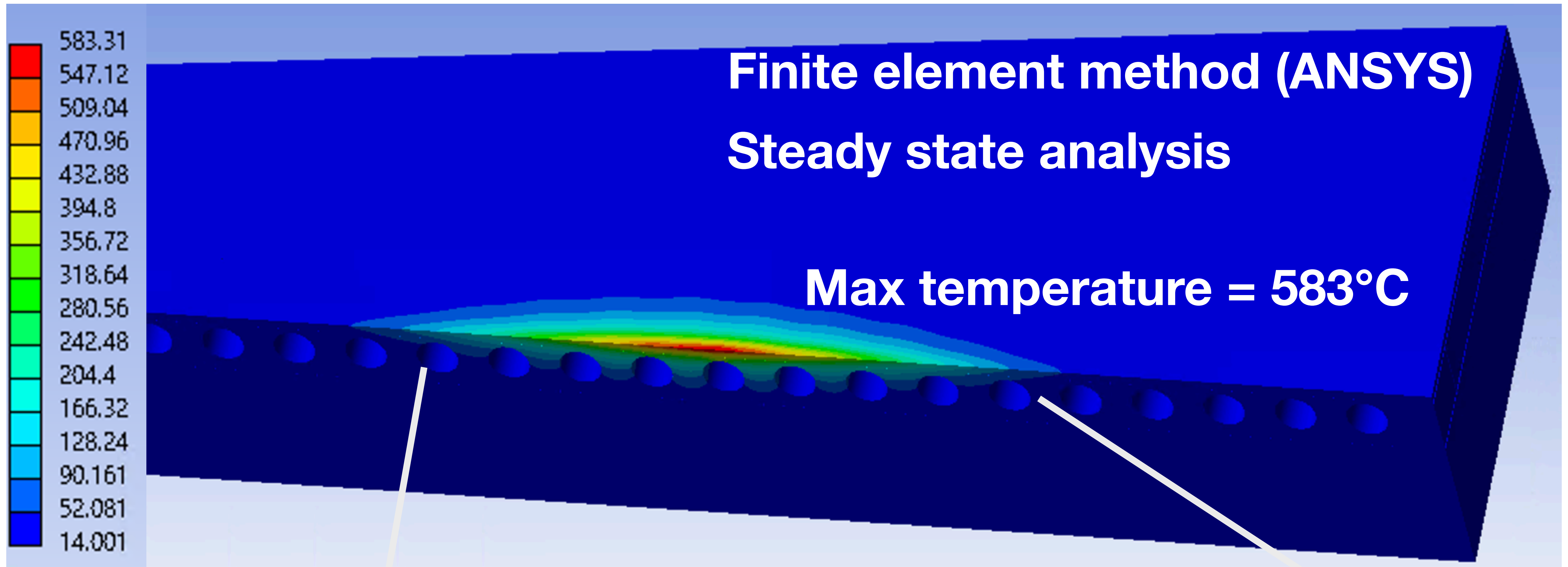


Beam

Spot size: $\sigma_x = 1.5$ mm, $\sigma_y = 3.6$ mm ← Beam profiles btw. SRC & F0

Position: -6 mm in vertical direction → **Beam hits bottom plate**

^{70}Zn range in dump: 8.3 mm

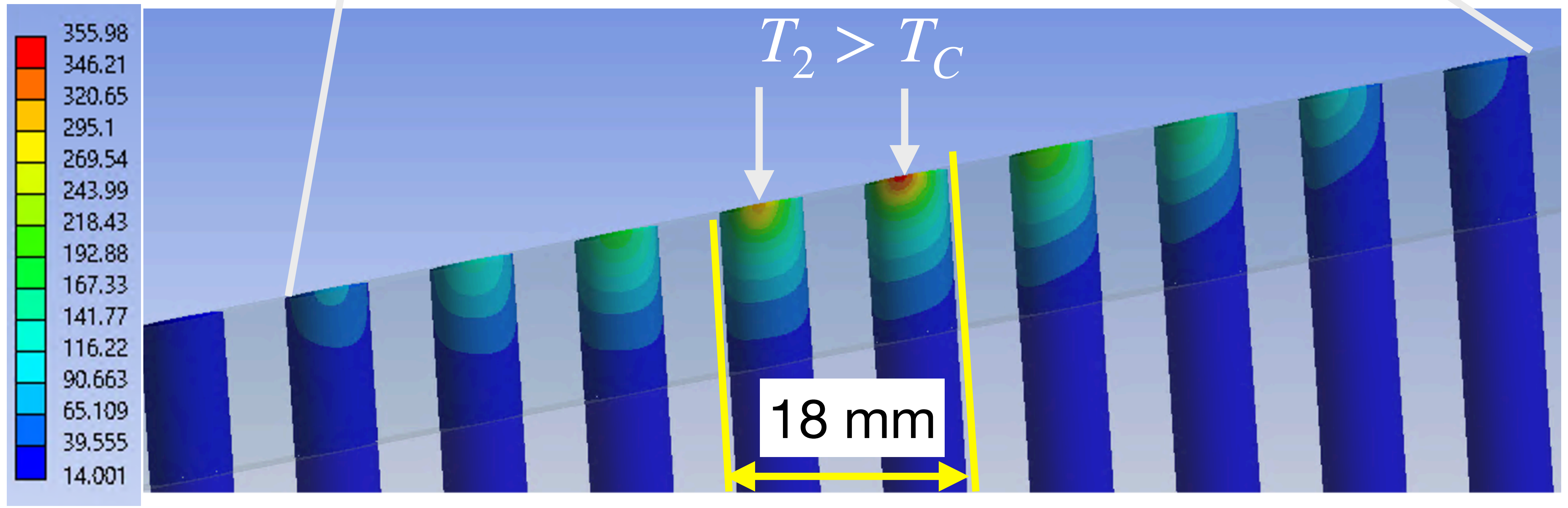


$T_2 > T_C$ (250 °C)

Dump is damaged

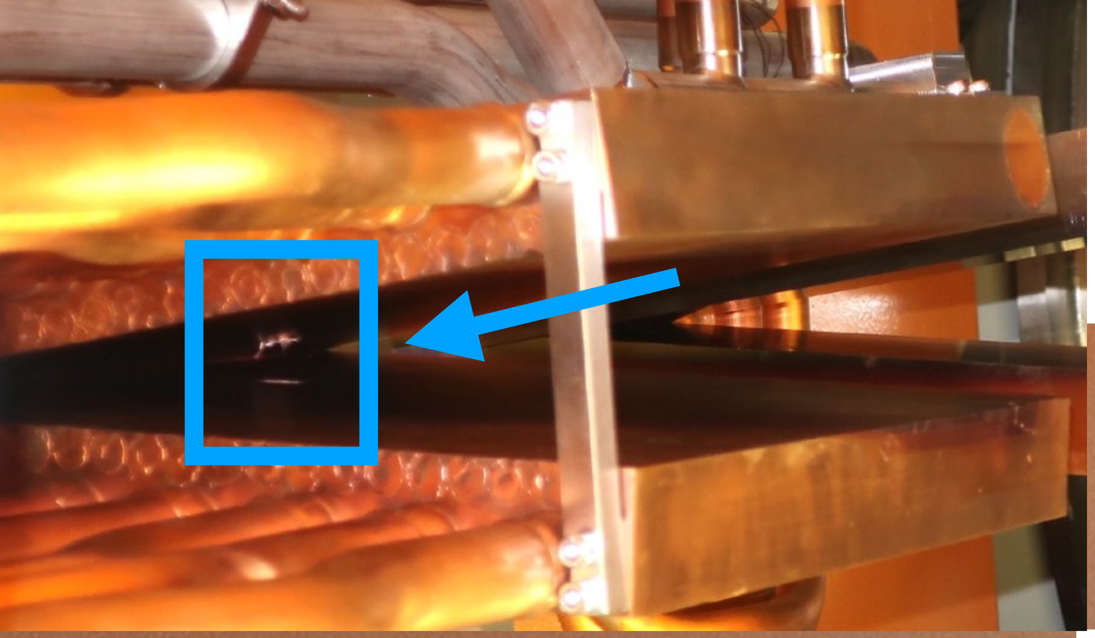
Tube surface T_2

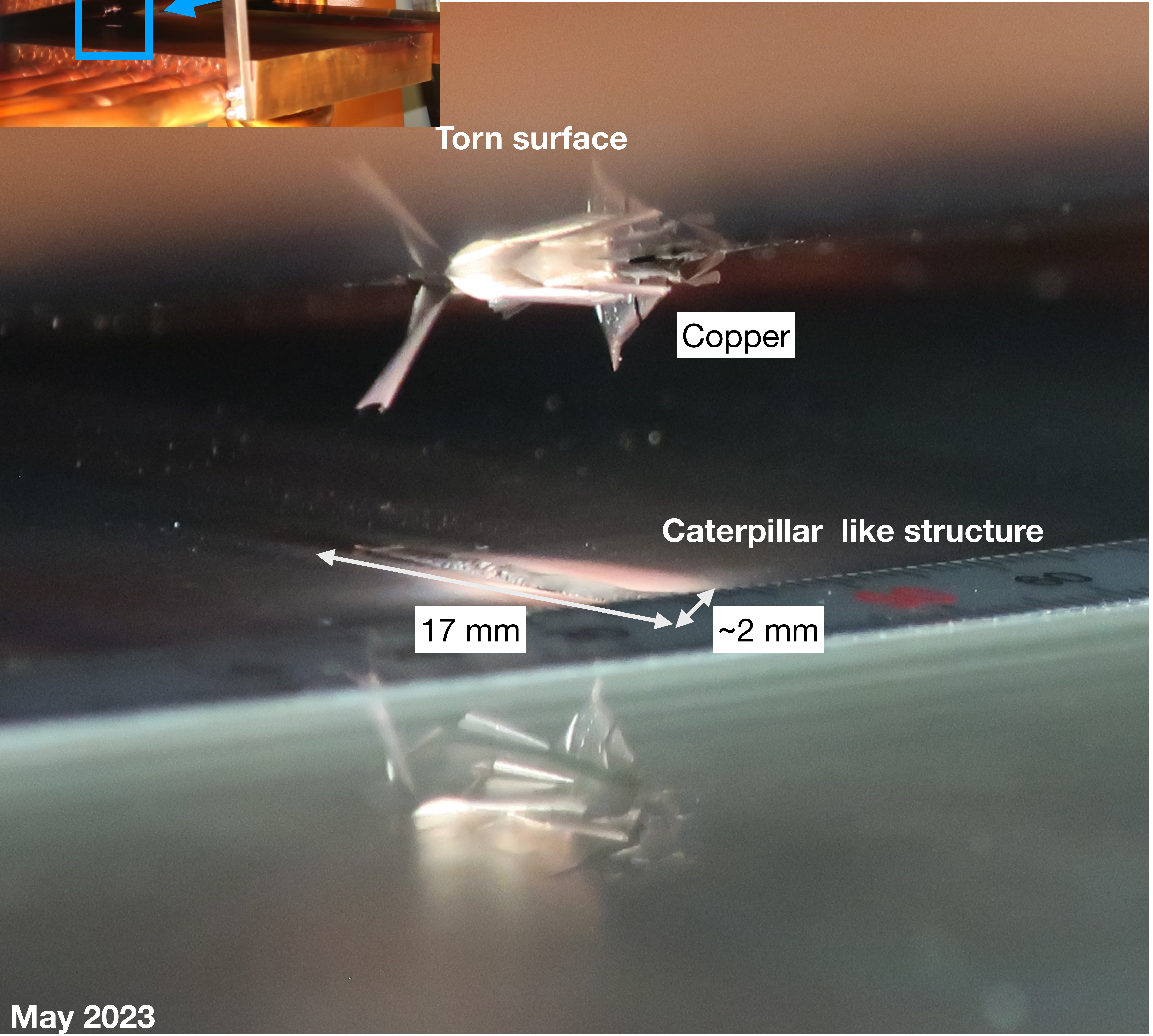
Max = 356°C



Caterpillar → molten mark by ^{70}Zn beam

Molten Mark on Dump by ^{70}Zn Beam





- Caterpillar → Molten mark by ^{70}Zn beam
  - Why not violently burned out?
- Torn surface → deposition of Cu vapor
  - Torn due to sudden cooling
- Causes: beam conditions & water flow
  - **vertical position: 6 mm below the center**
  - size: smaller than expected
- Water flow speed was 6 m/s.
- **We will keep using this exit dump**
  - No water & vacuum trouble
  - ~2 years to build new exit dump

May 2023

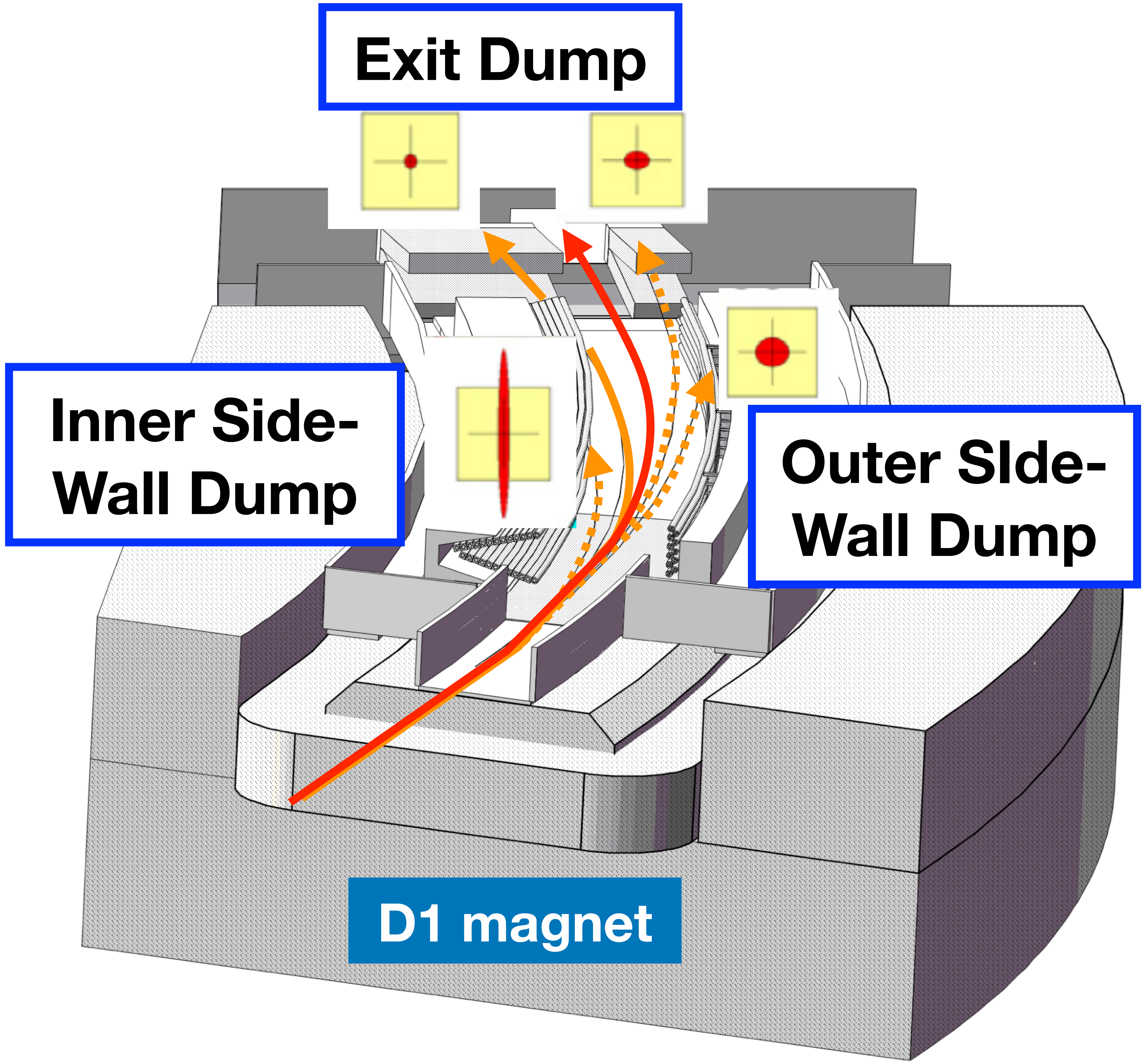
Summary and Outlook

- The beam dumps of BigRIPS
  - 3 different beam dumps inside and downstream of first dipole magnet.
  - $<$ 20 kW beams have been intercepted.
- Found a molten mark on the exit beam dump in 2023.
  - The ^{70}Zn beam irradiated in the autumn 2022.
    - Shift of vertical position + Small spot size + slow water flow speed.
  - Keep using this dump at least in 2 years.

- New exit dump is under development to cope with ~160 kW beams
  - Future upgrade of RIBF

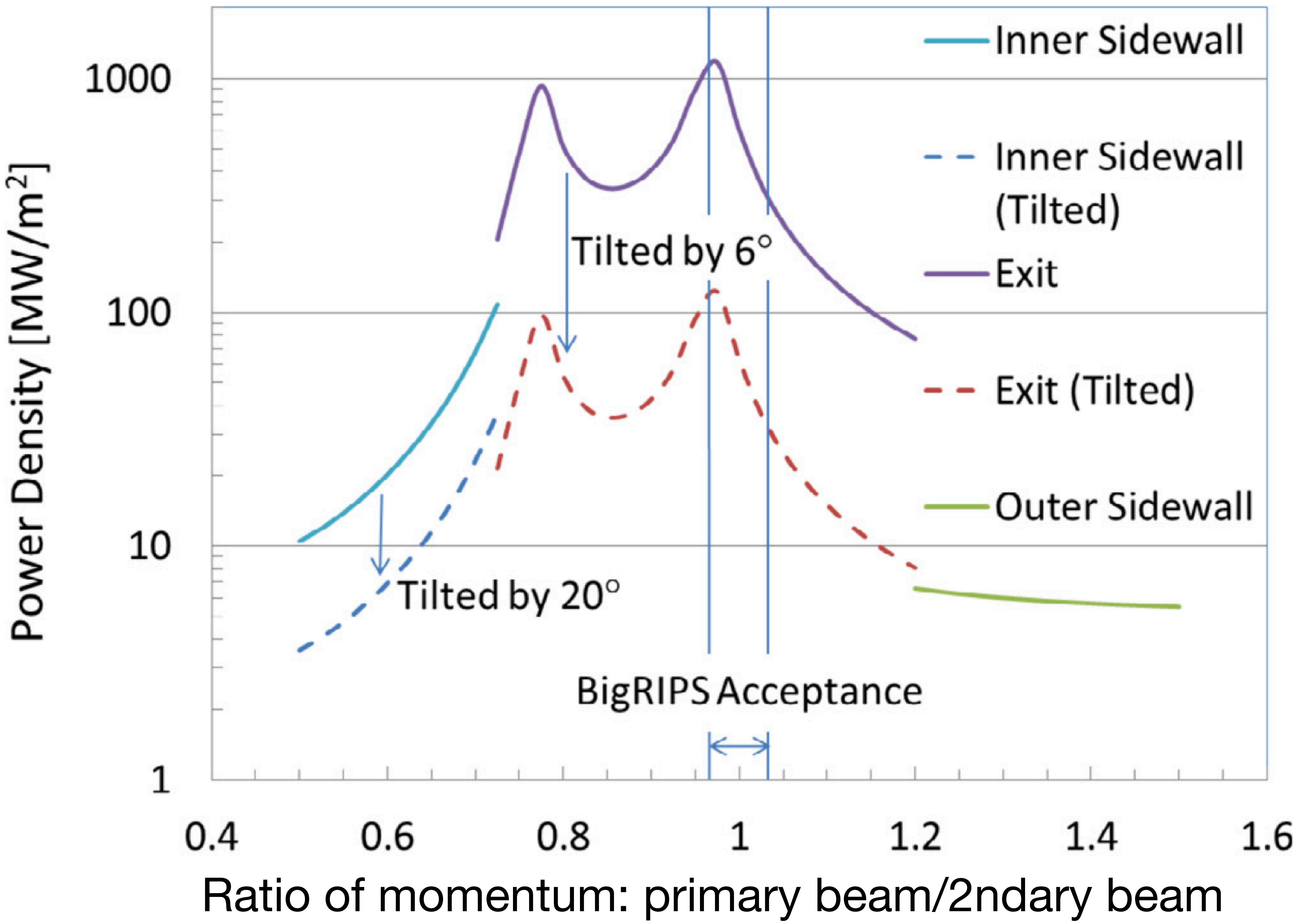
Backup slides

Heat Flux Depends on Hit Positions



^{238}U 345 MeV/nucleon, 1pμA (82 kW)

K. Yoshida et al., NIMB 317, 373 (2013).



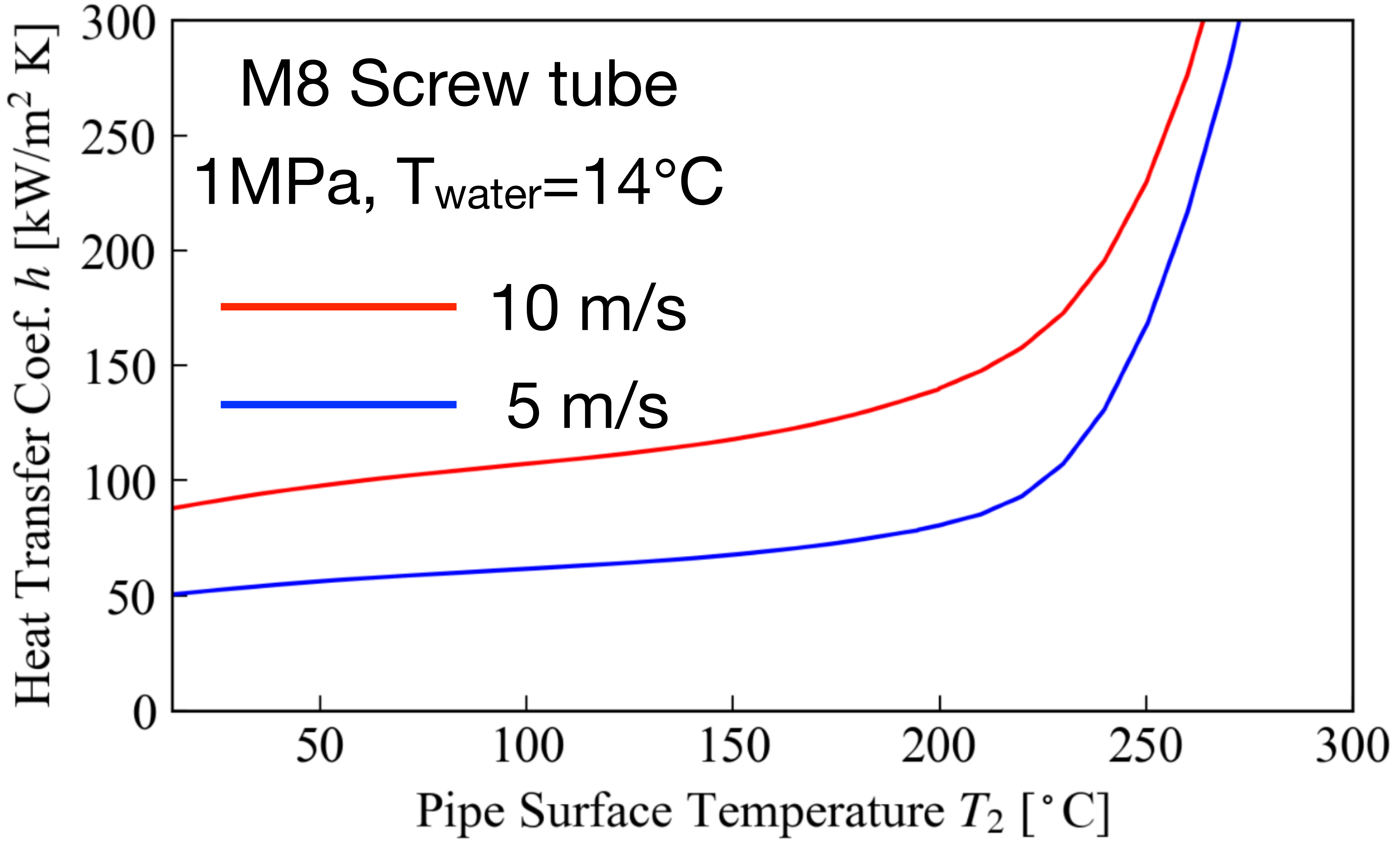
60 MW/m² ~ surface of the sun

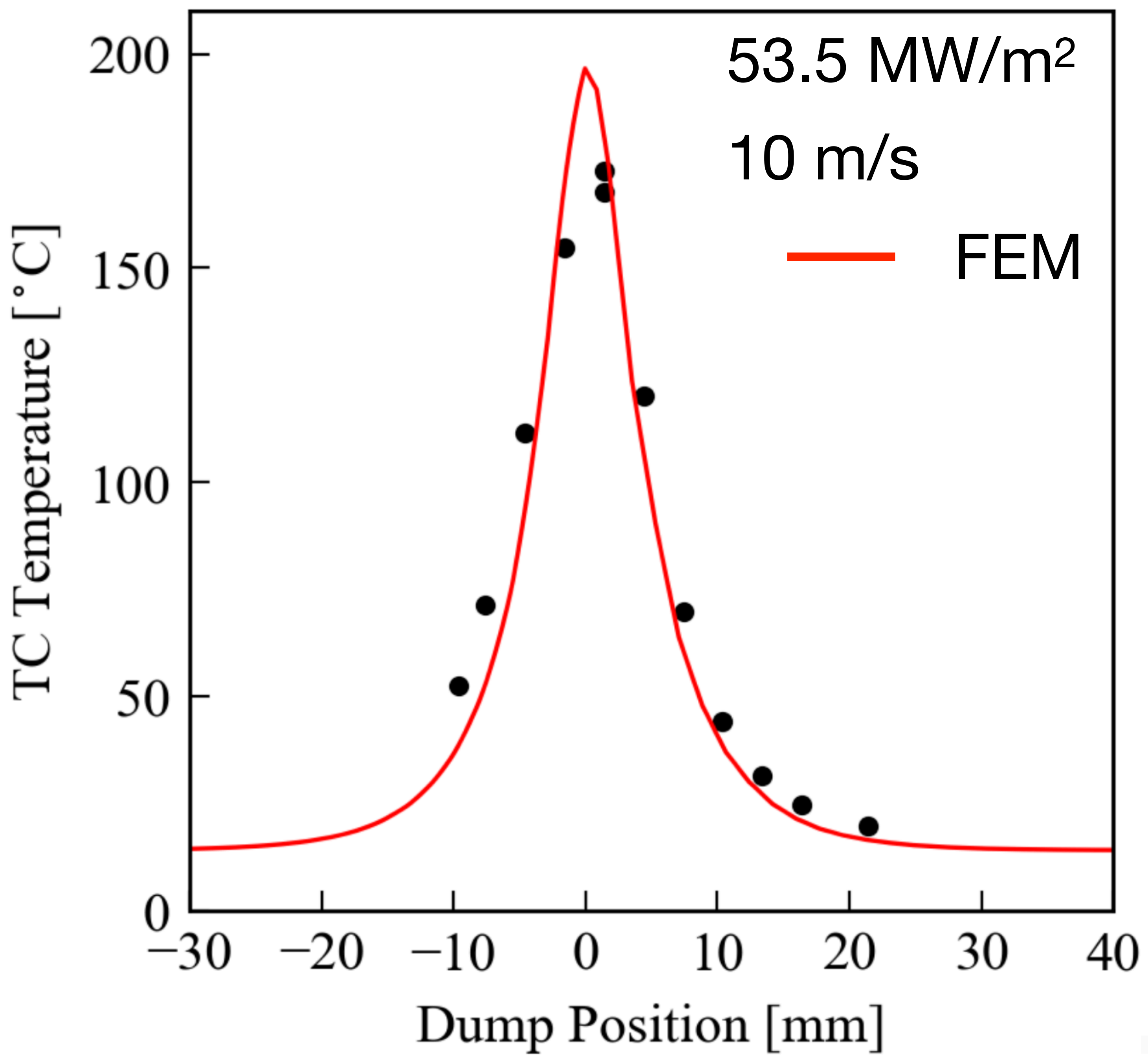
Temperature measurement with ^{48}Ca

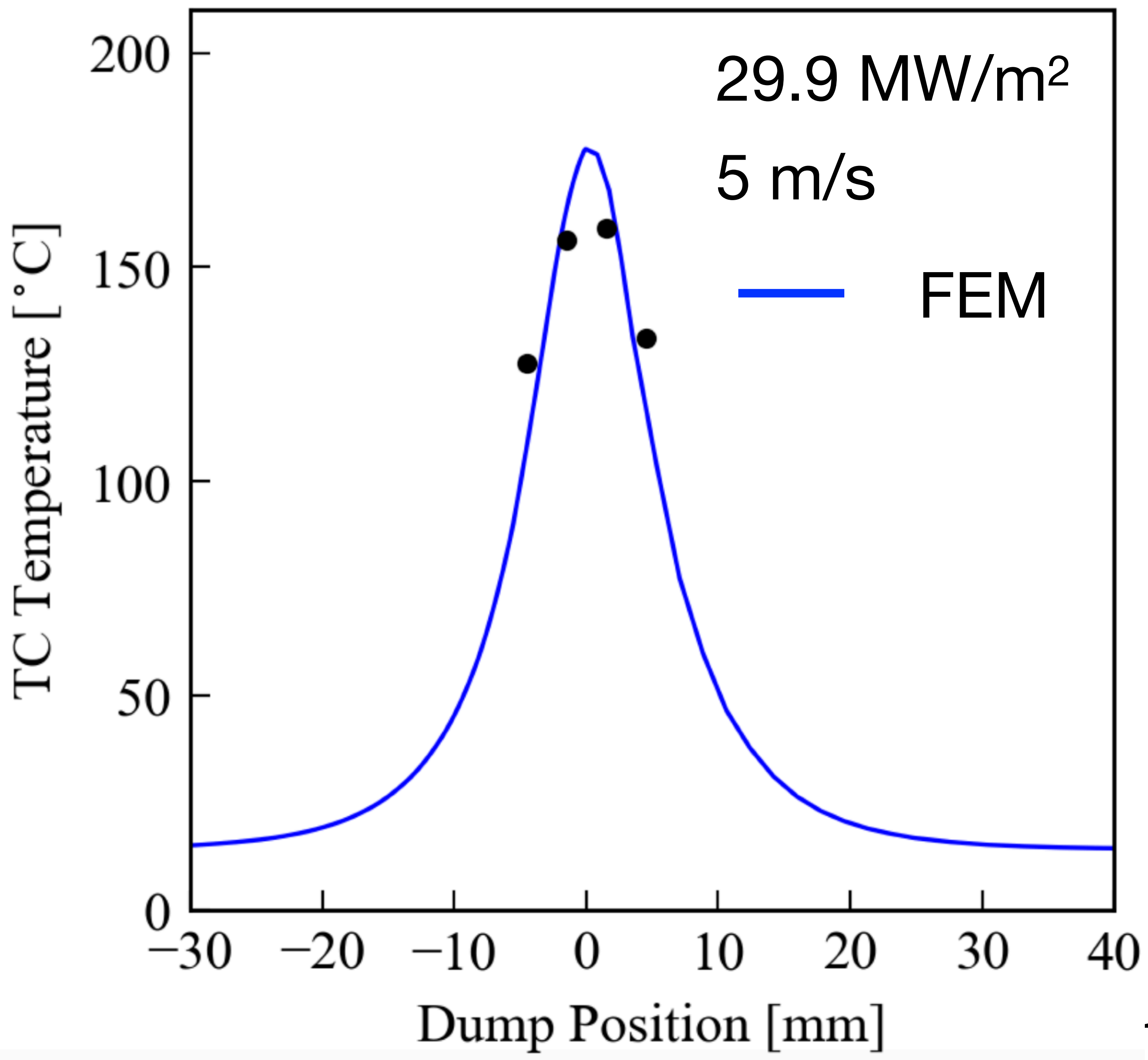
Thermal conductivity of CuCrZr: 320 W/m K

http://conductivity-app.org

Beam spot size (mm^2)	1.9 x 23.6	3.0 x 27.2
Heat Flux (MW/m^2)	53.5	29.9
Max temp (℃)	310	273
Max temp at water pipes (℃)	156	172
Max temp at thermocouple (℃)	197	177

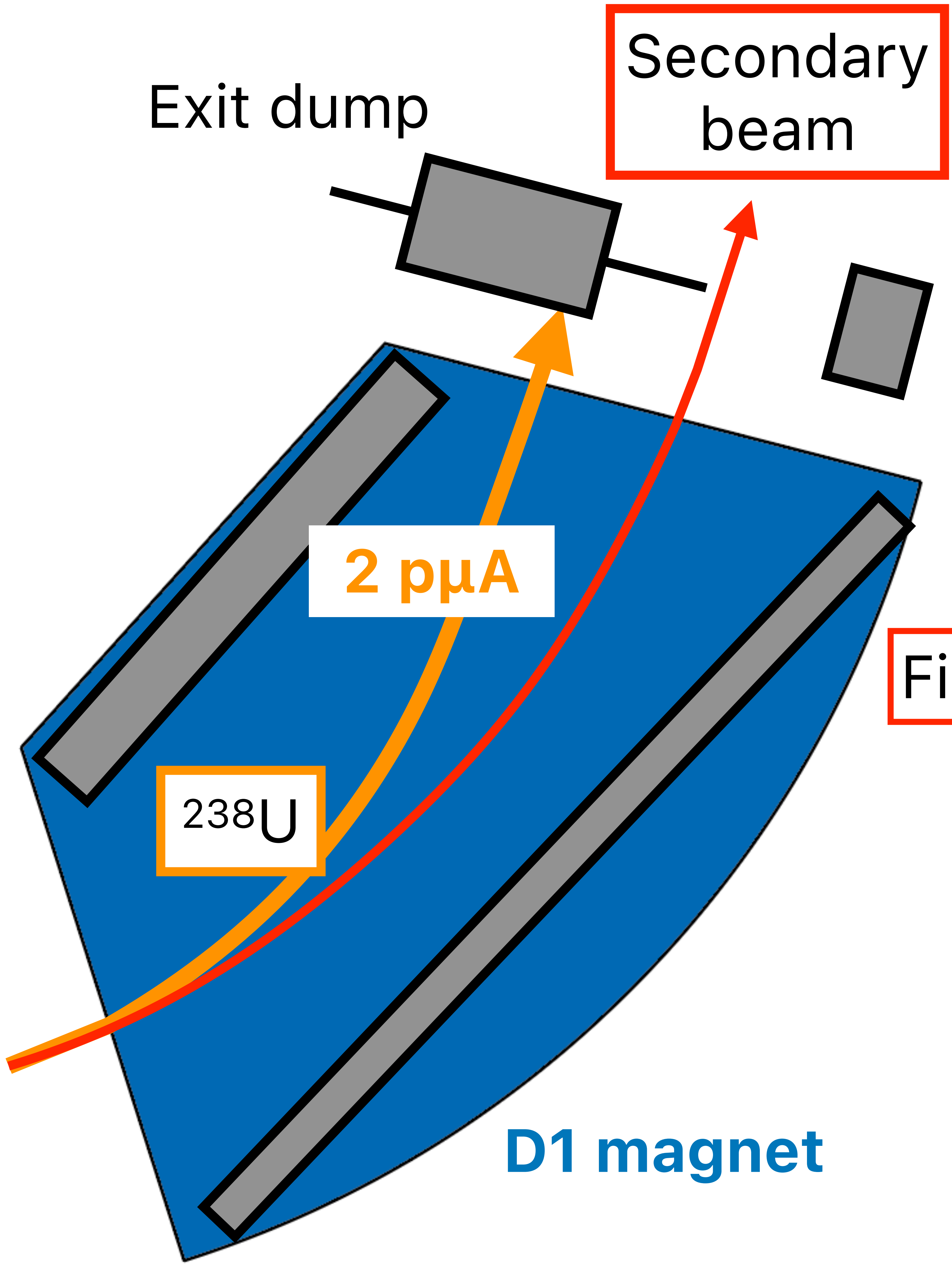


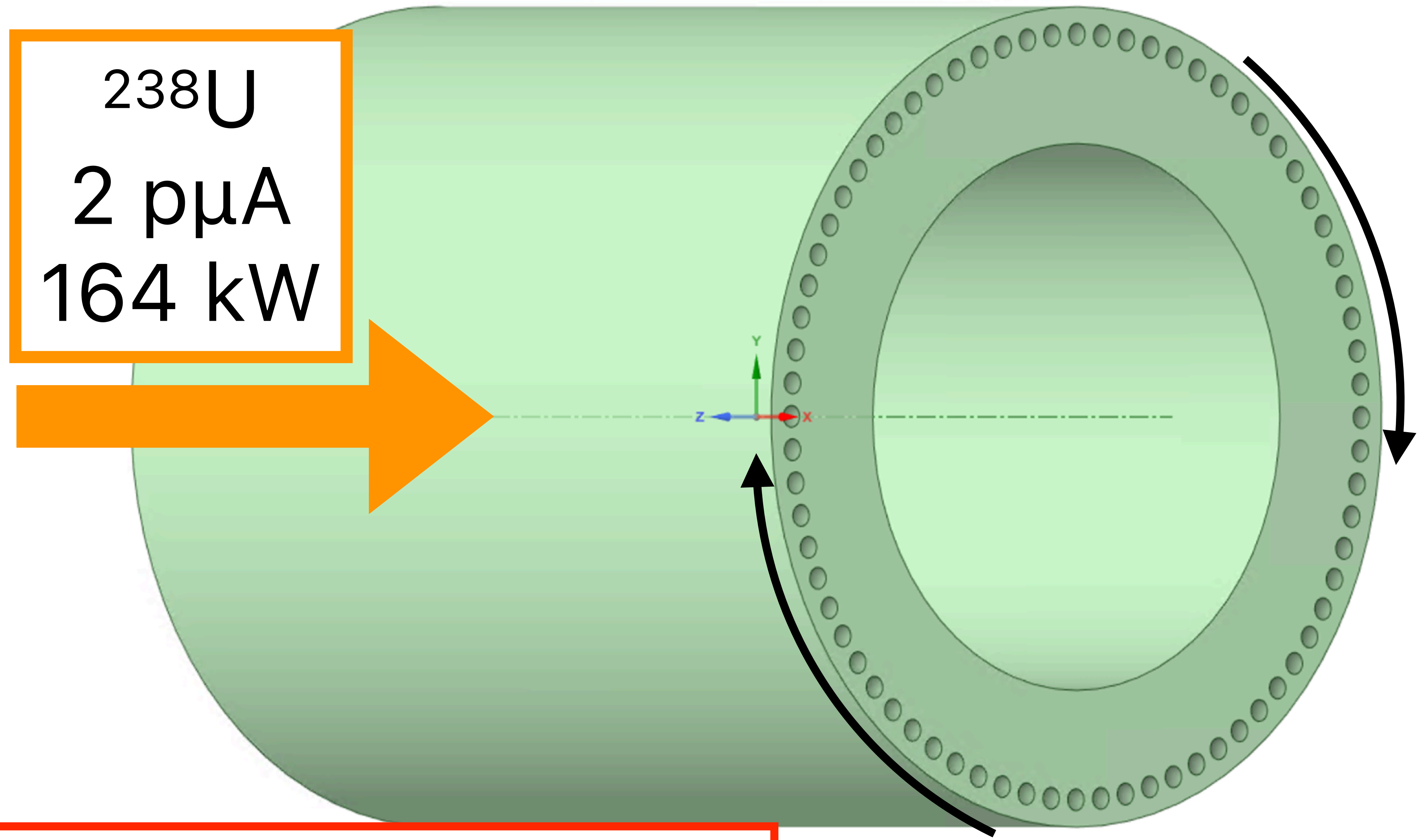




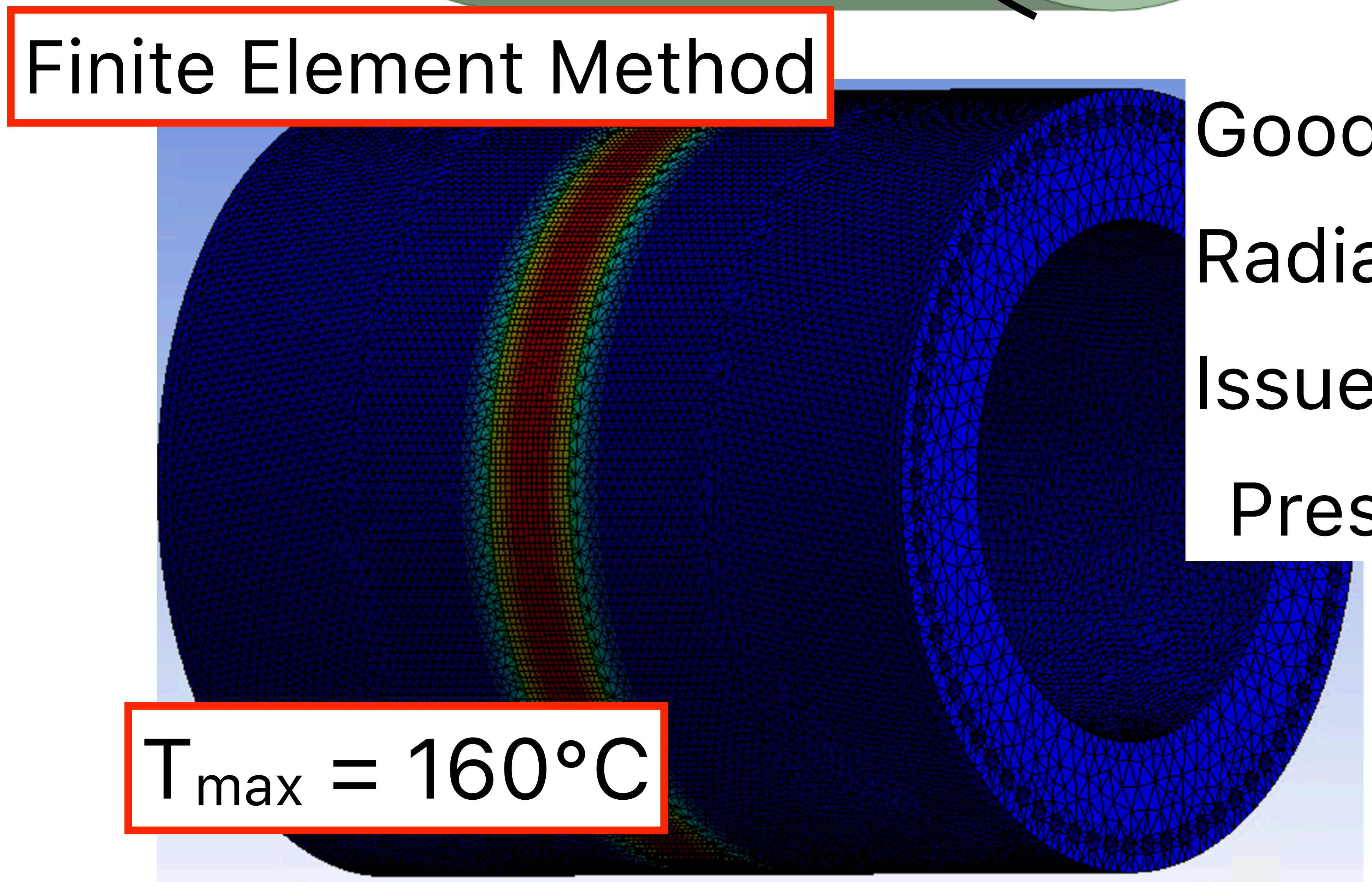
New Exit Dump: Rotating Drum

Smaller heat flux by effectively enlarging the beam irradiated area





- 300mm ϕ
- CuCrZr alloy
- 72 M8mm Screw tubes
- 100~200 rpm

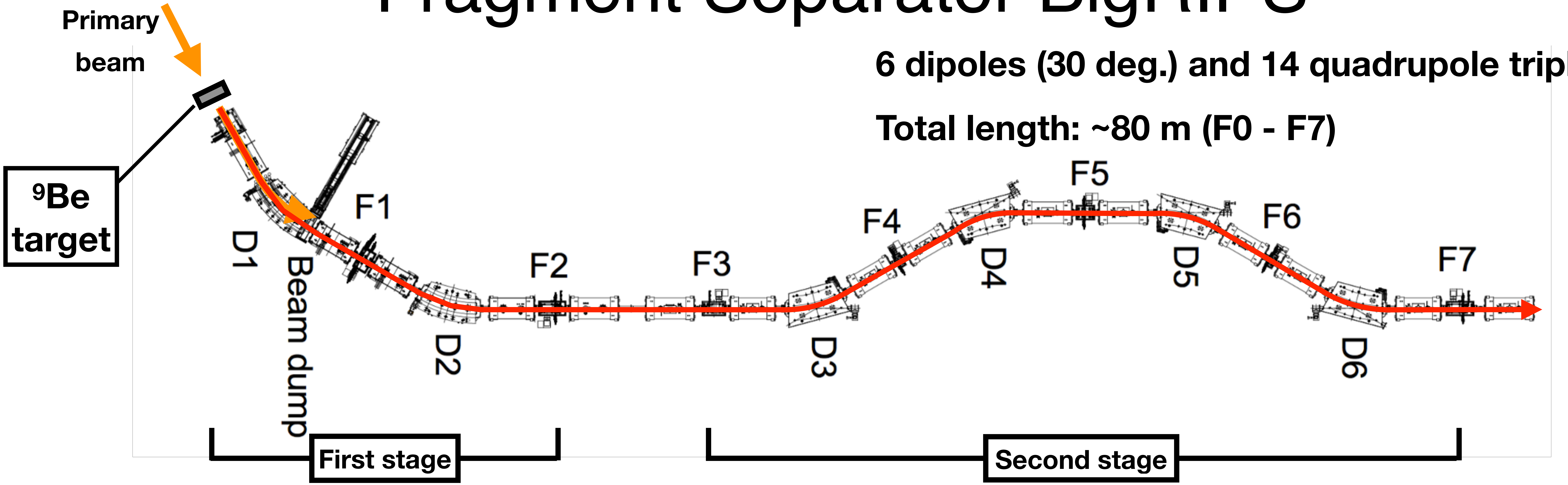


- Good cooling capability
- Radiation damage: ~0.3 DPA/day
- Issues
  - Pressurized water to rotating object

Fragment Separator BigRIPS

6 dipoles (30 deg.) and 14 quadrupole triplets

Total length: ~80 m (F0 - F7)



Production

Separation

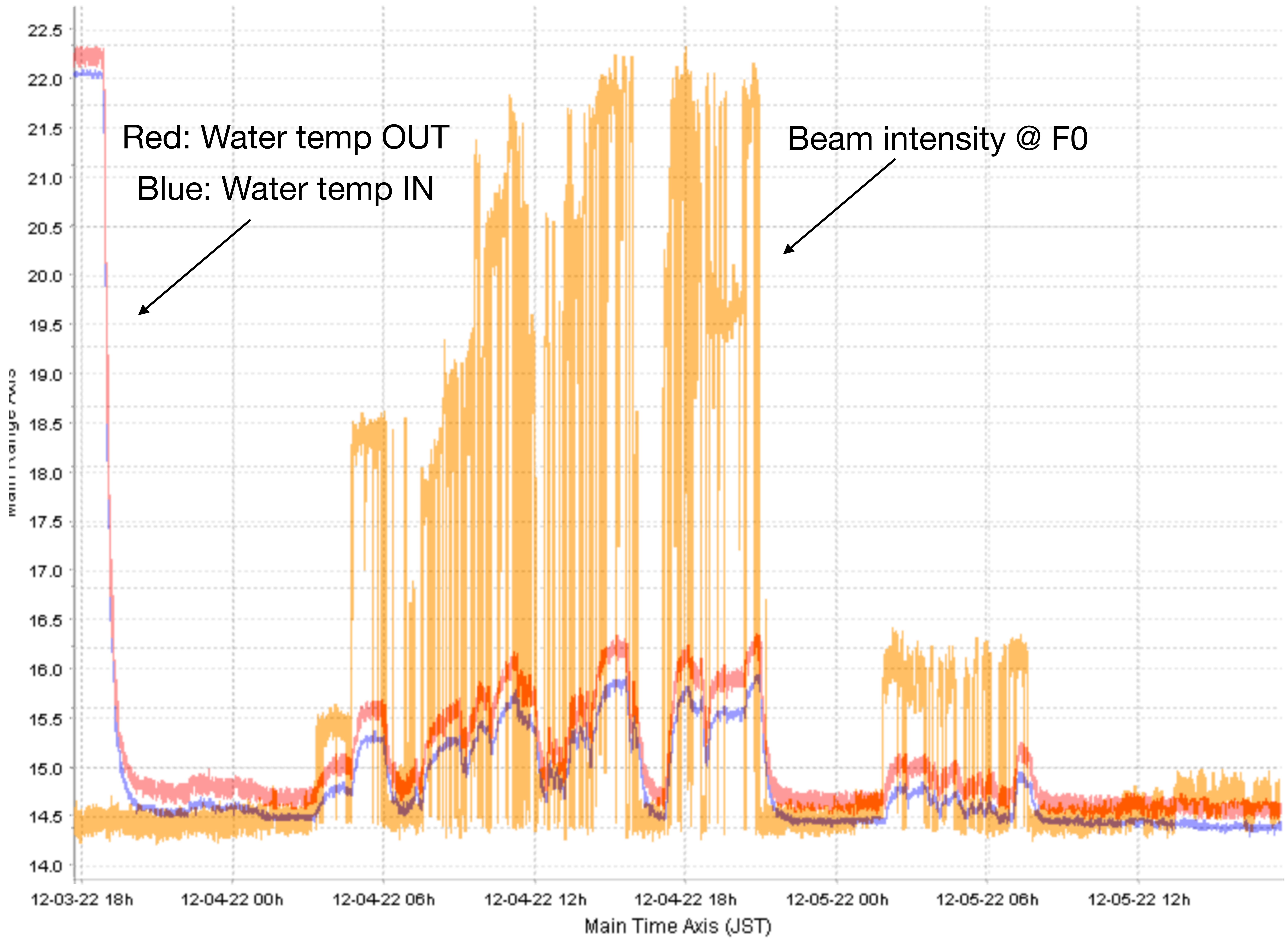
Event by Event particle identification

Further separation

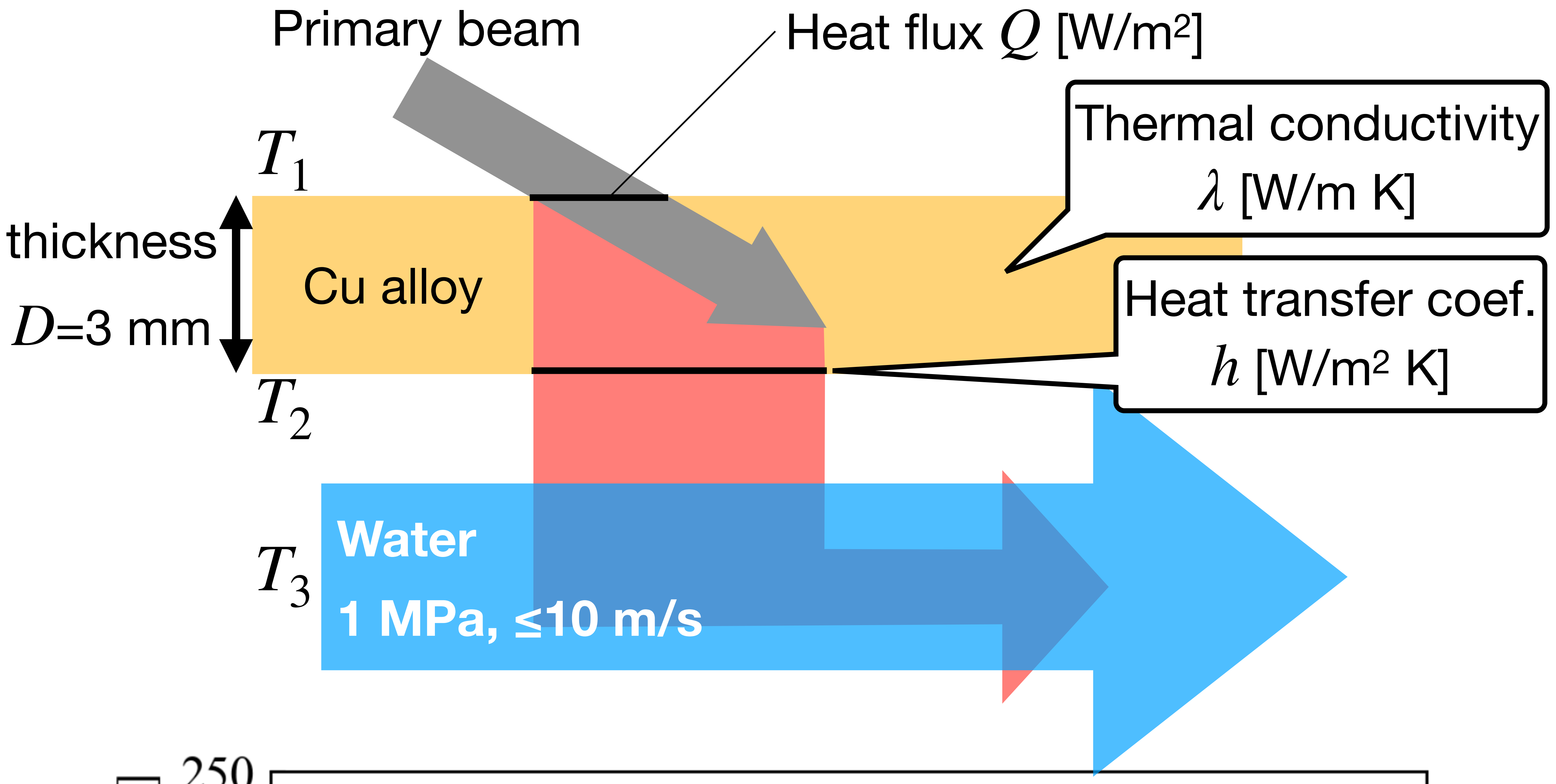
Large acceptances

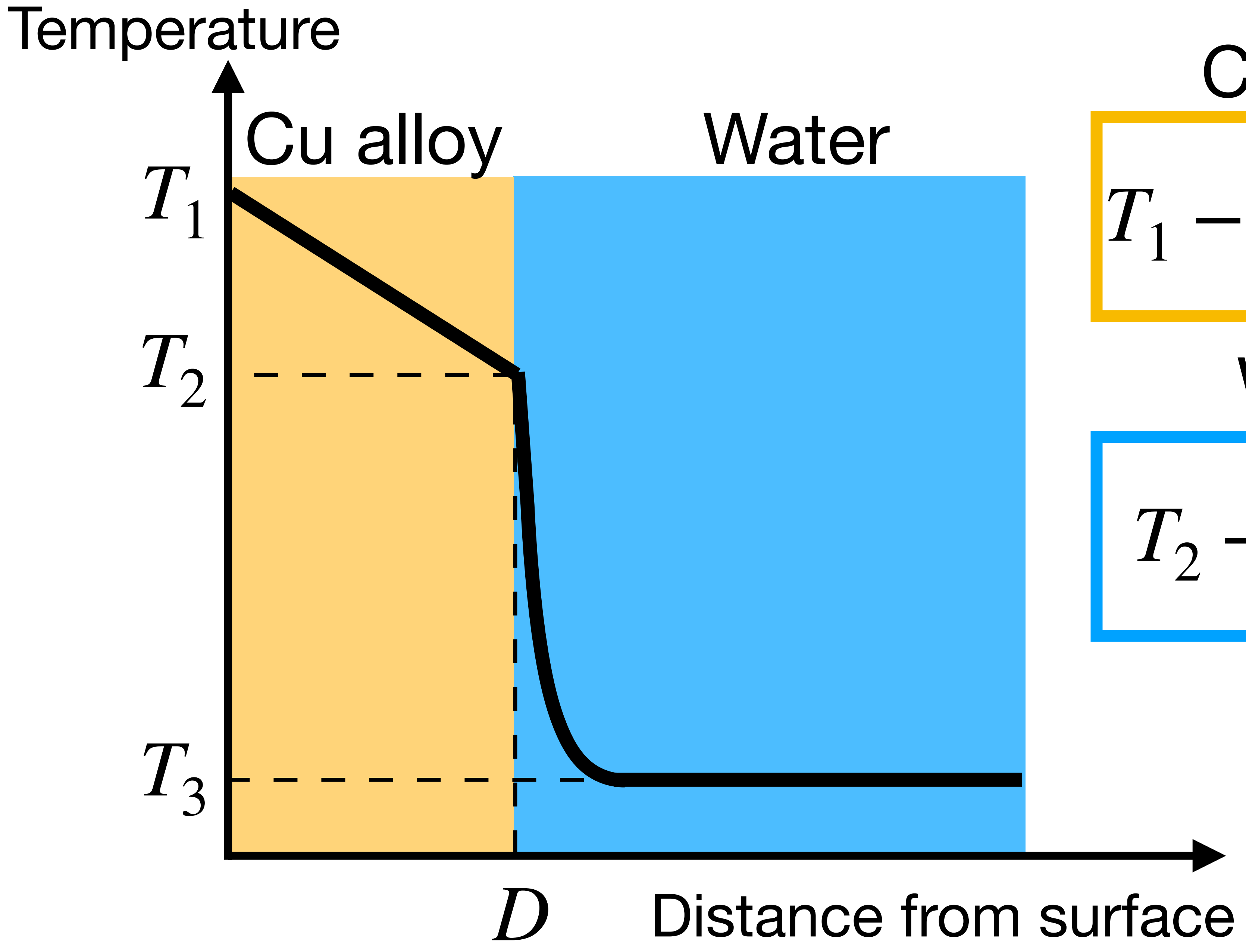
$\Delta\theta = \pm 40$ **mrad,** $\Delta\phi = \pm 50$ **mrad,** $\Delta p/p = \pm 3$**%**

Beam Intensity & Water Temp. during Accelerator Tuning



Cooling the Dump: Heat Transfer to Water





Cu alloy

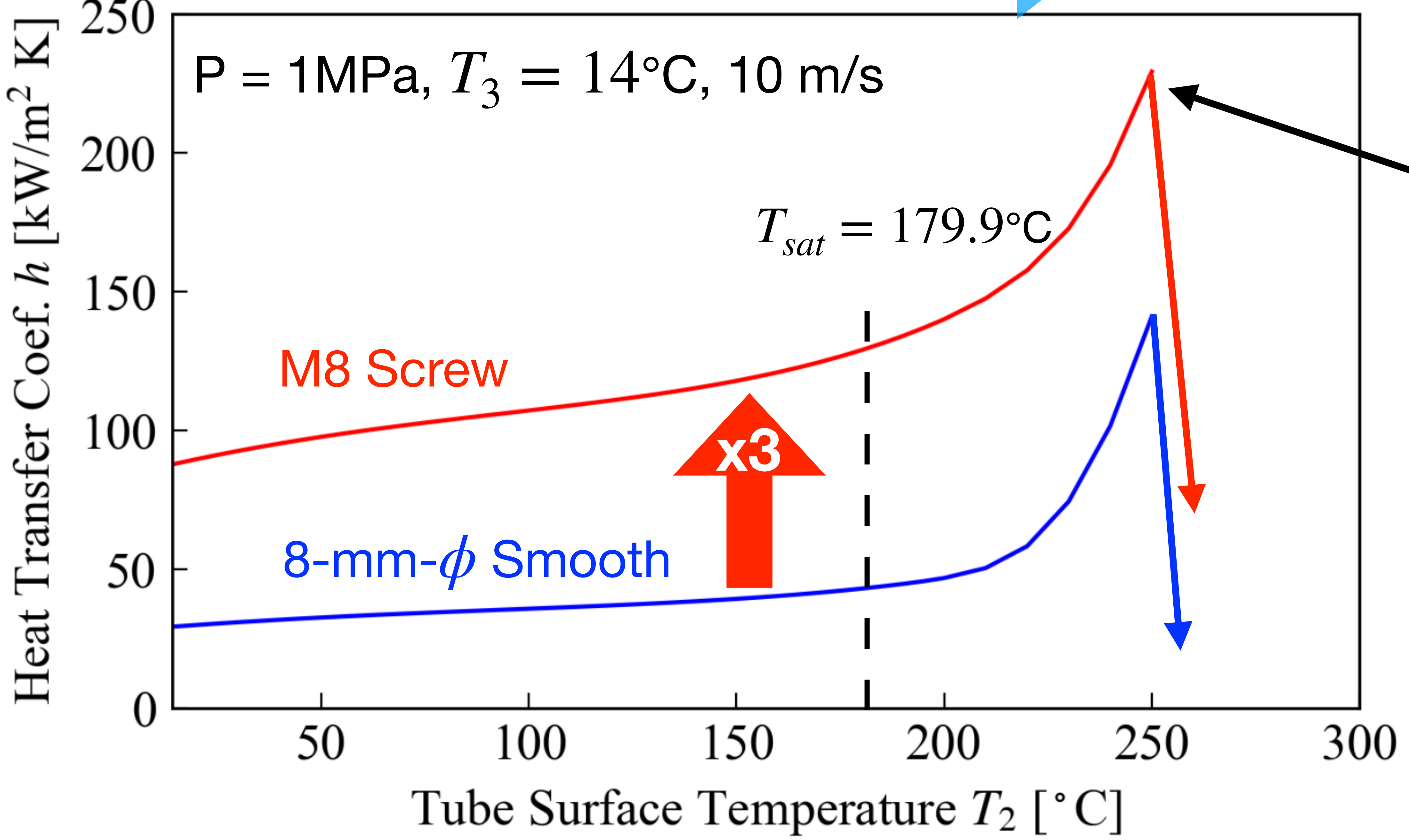
$$T_1 - T_2 = \frac{DQ}{\lambda}$$

Water

$$T_2 - T_3 = \frac{Q}{h}$$

Q : Beam condition

h : Water condition



Critical temperature: $T_C \simeq 250$°C

Water tube: covered with vapor ← vigorous boiling

→ Much reduced heat transfer rate

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