High Power Targets for FRANZ

Micaela Fonseca

496. WE-Heraeus-Seminar:

Astrophysics with modern small-scale accelerators

Outline

- Motivation
- Challenges of high power target design
- Thermal Evaporation for the thin films preparation
- Neutron high power target
- Experiment at GSI to measure the temperature
- Proton high power target

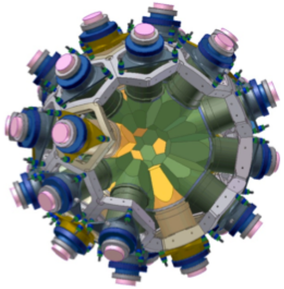
- Motivation

Motivation

Energy-dependent neutron capture cross section measurements

Cross sections of (p,γ) reactions for p Process.

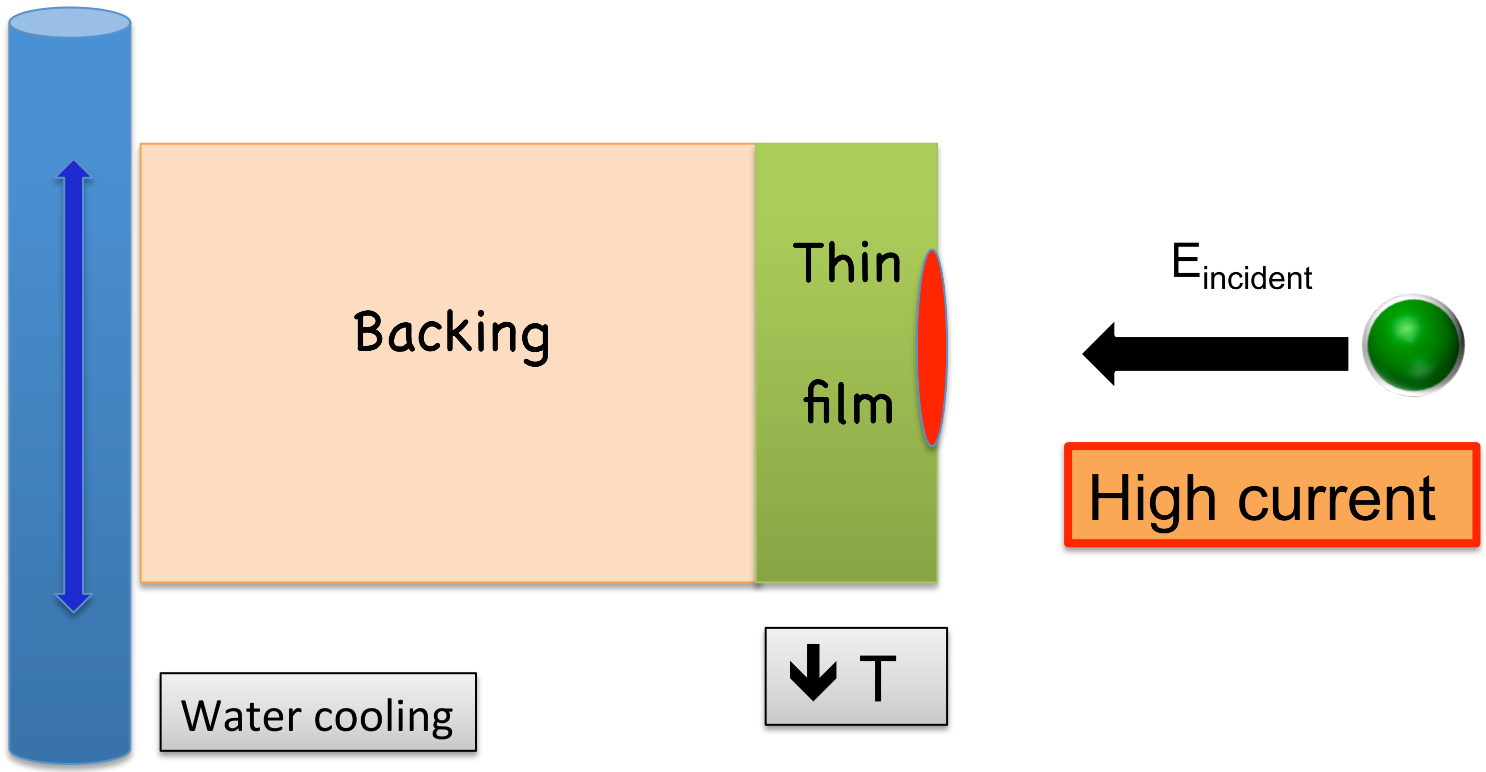
Three essential ingredients have to be optimized:

- Beam intensity → FRANZ Facility
- Detector efficiency →  4π BaF_2
- Target quality

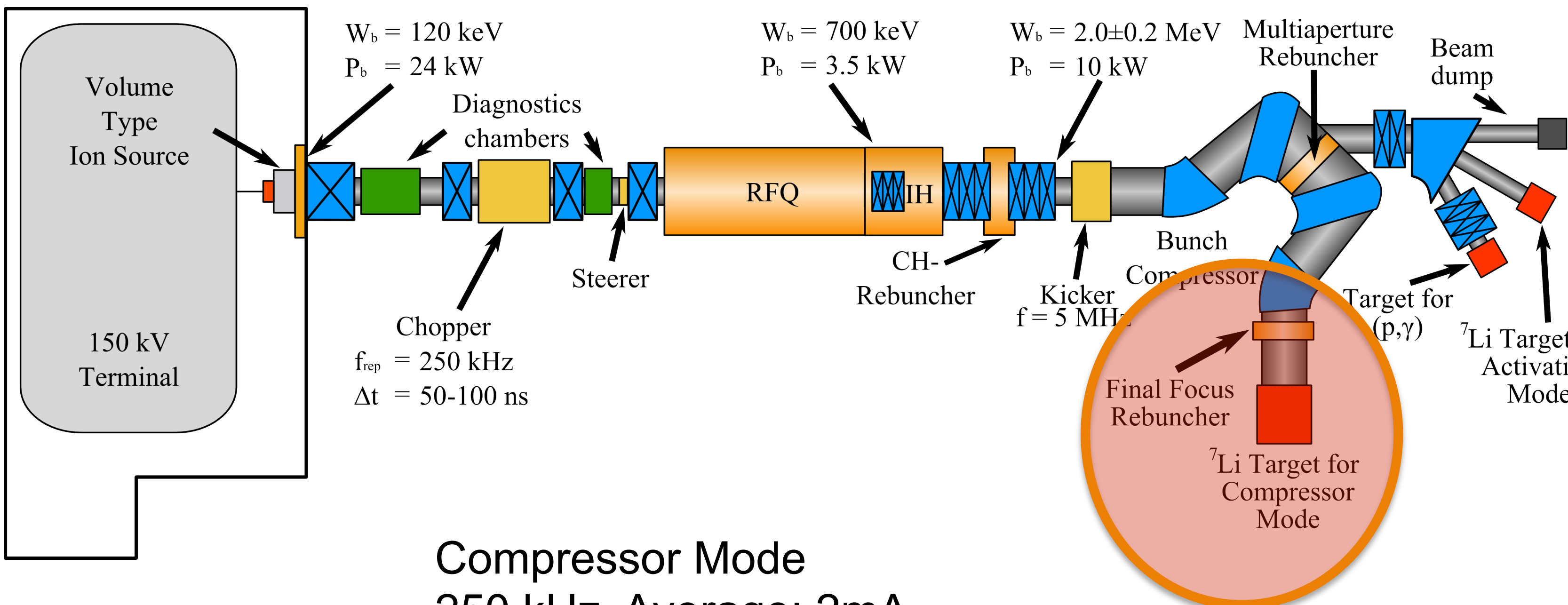
- Motivation

- Challenges of high power target design

The principal concept of the high-power target is as follows:

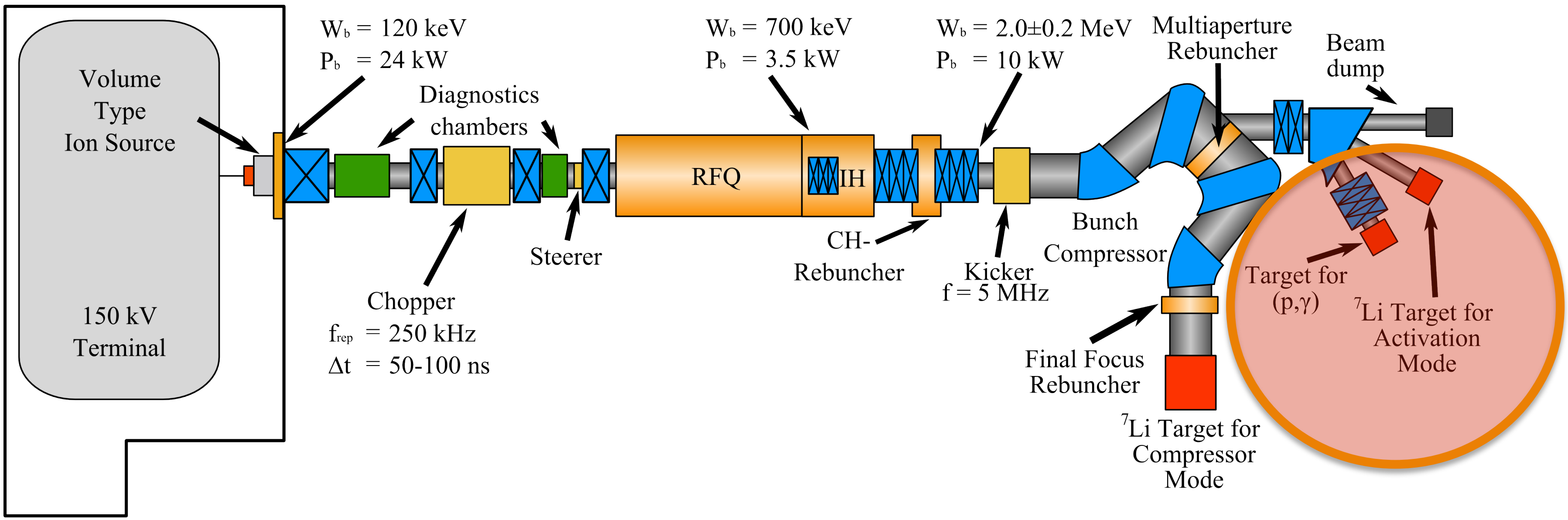


FRANZ Facility



Compressor Mode
250 kHz, Average: 2mA
< 1ns pulse width
neutron flux at 1 m: 10^7 s^{-1} cm^{-2}
neutron flux at 0.1m: 10^9 s^{-1} cm^{-2}

FRANZ Facility



Continuous mode and for (p,γ) measurements:

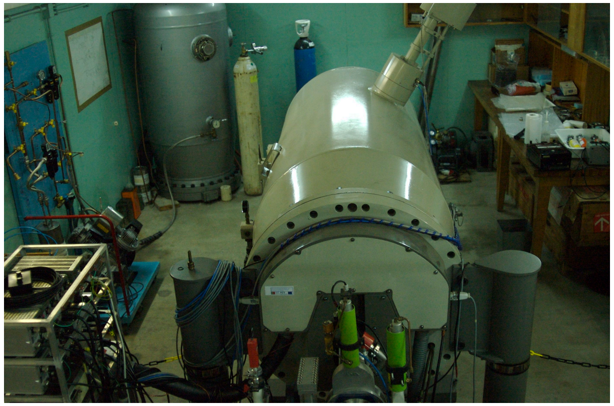
continuous proton beam of up to 20 mA

Enormous heat load of up to 100 kW/cm^2 has to be handle

Target has to be able to absorb the beam power COMPLETELY!

→ How is the thin film going to be prepared?

→ What is the most suitable backing material?



Van der Graaff and Tandem accelerators

Energy: 100 – 5000 keV

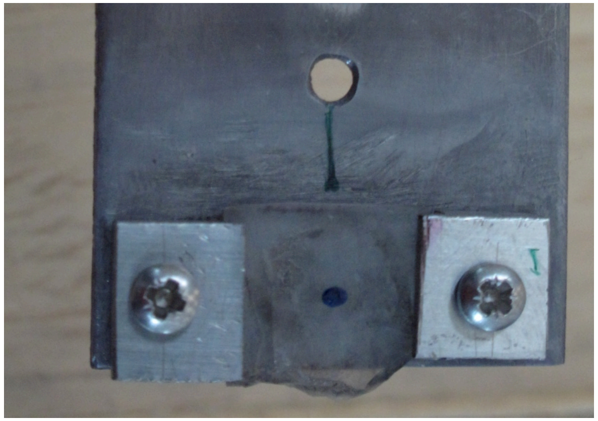
Proton beam currents:

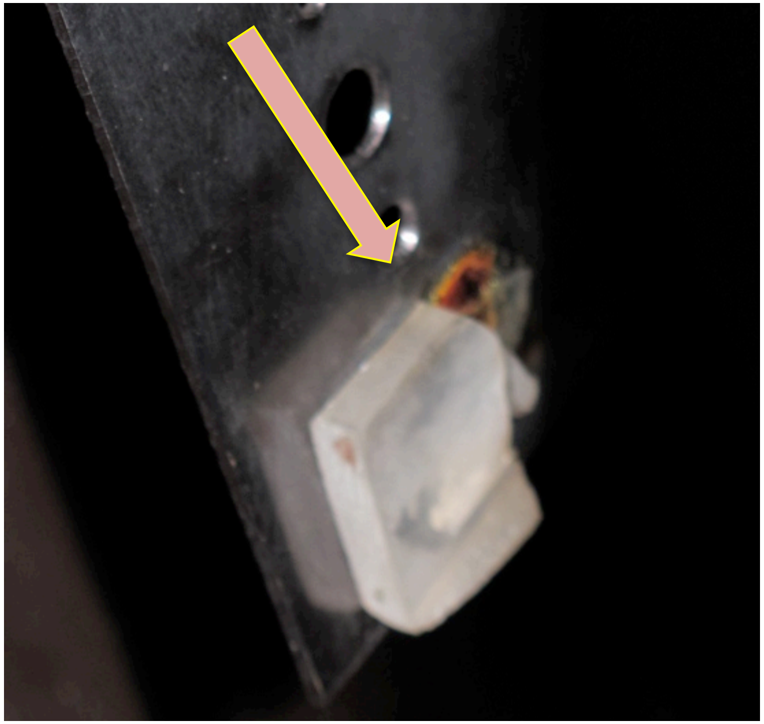
- 1-100 nA : Ion Beam Techniques
- up to 2 μA : cross section measurements

FRANZ Facility Factor of ~1000 higher!

Prototype: high current

2 mA, 4 kW proton beam

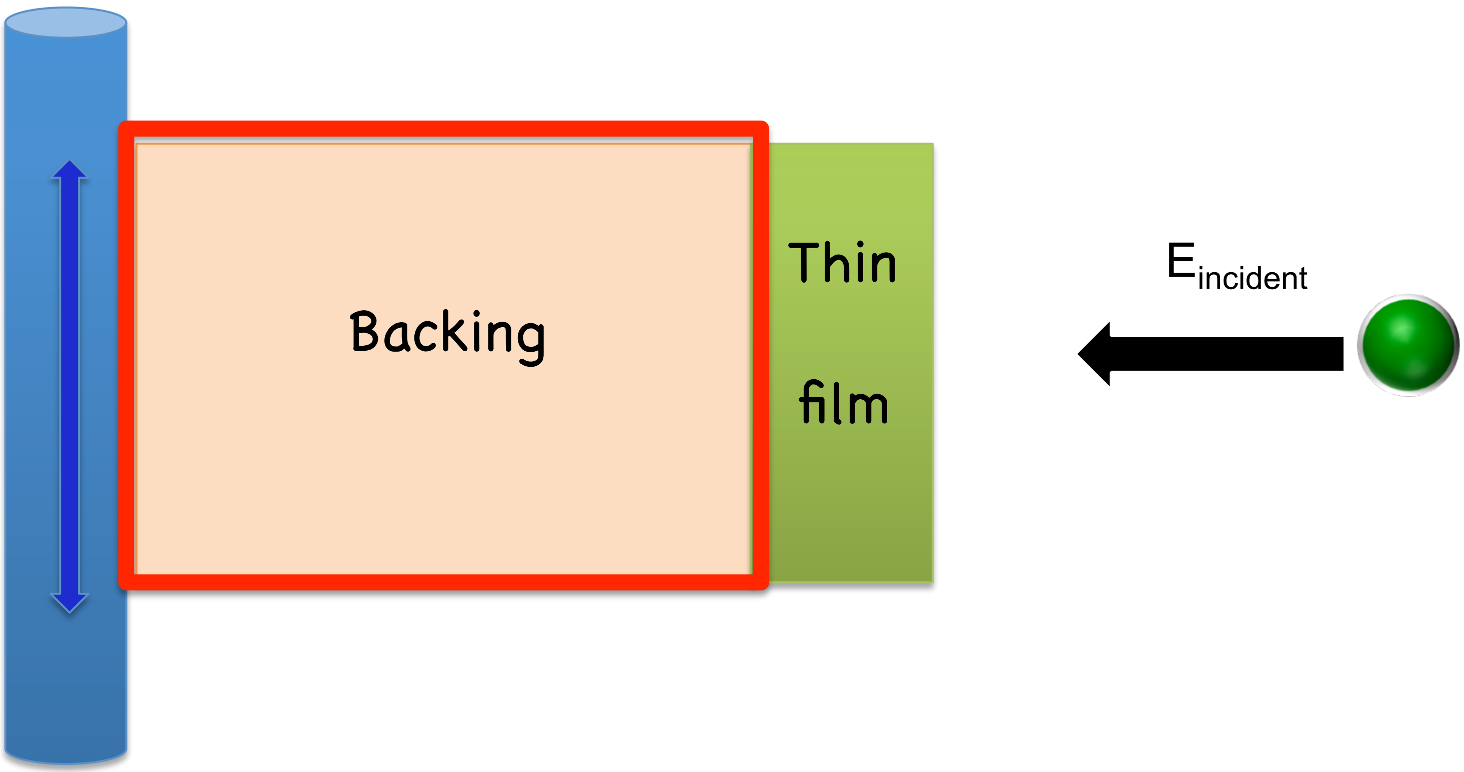




1 μA

2 mA

Factor of ~1000 higher!


Backing
Thin
film
$E_{incident}$

Ideal material for the backing:

High Stiffness and High Heat Conductivity

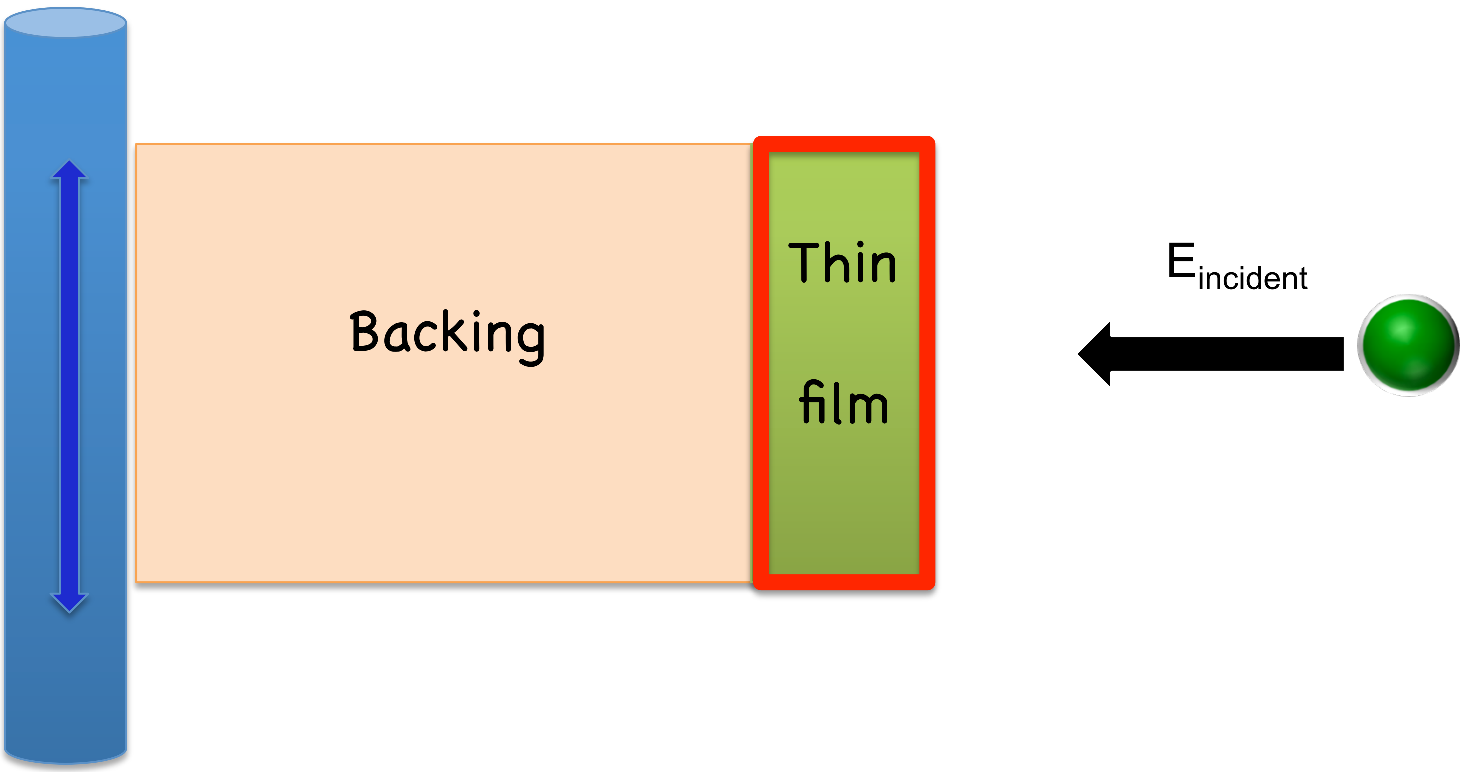
↳ to withstand water pressure of the cooling system

↳ to withstand the thermal stress induced by beam heating

No bending! → Geometry; vacuum…

Backing

- Foil
  - Neutron high power target: Copper foil
  - Proton high power target:
    - Choice: Depending on the element in study
- ~~Self-supporting thin film~~


Backing
Thin film
$E_{incident}$

- Motivation
- Key challenges to high power target design
- Thermal Evaporation

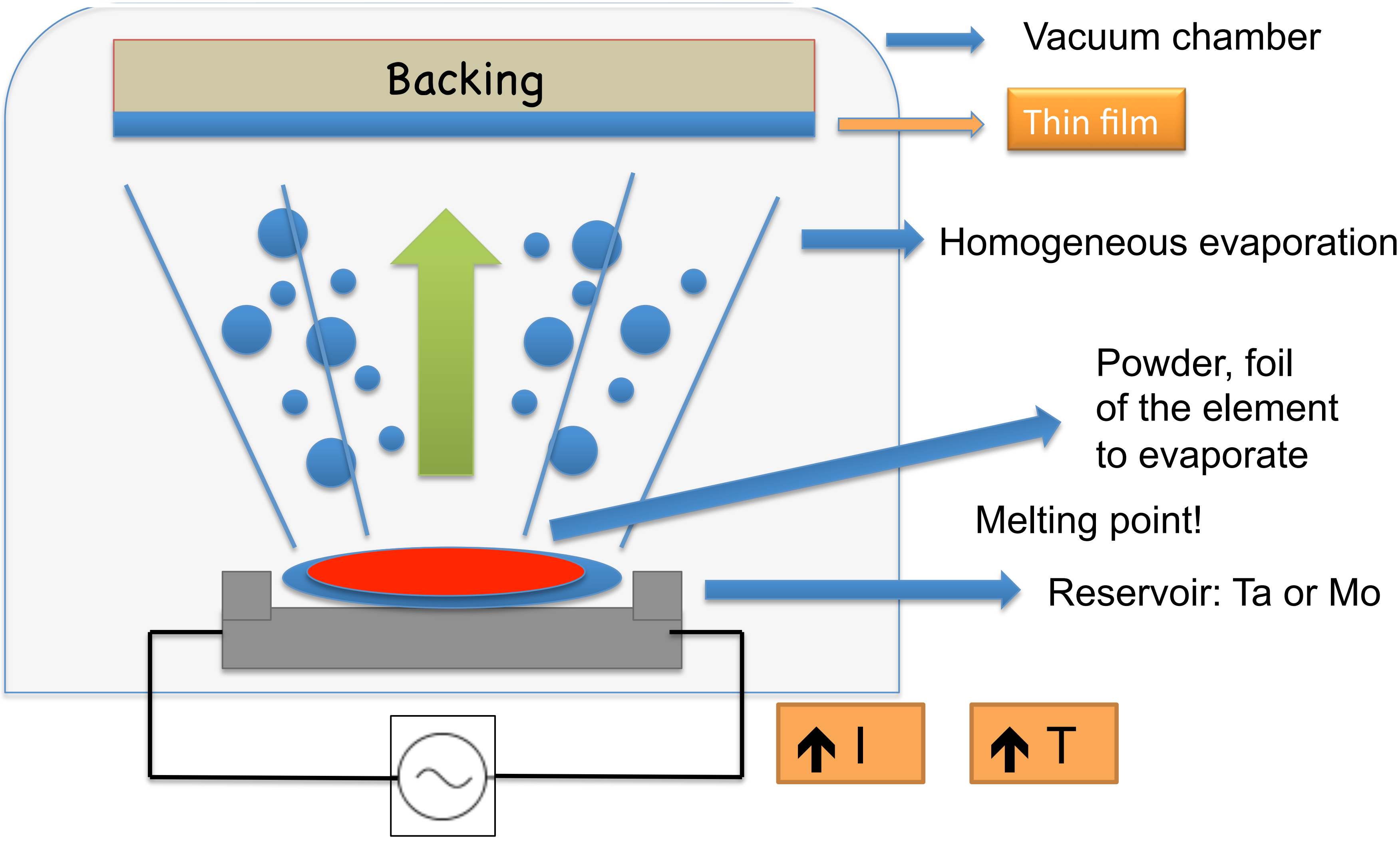
Chamber

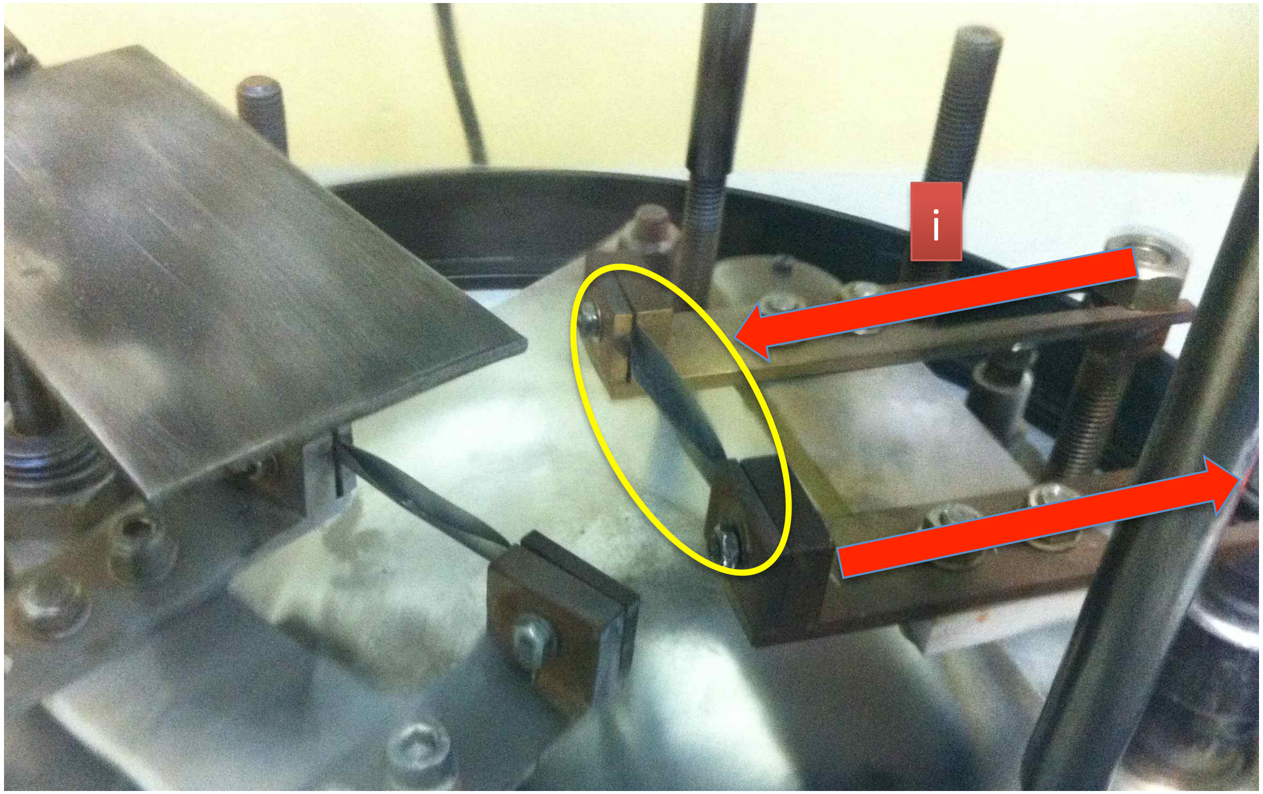
Transformer

Vacuum Pumping system

Diffusion pump

No turbulence


Backing
Vacuum chamber
Thin film
Homogeneous evaporation
Powder, foil
of the element
to evaporate
Melting point!
Reservoir: Ta or Mo
I
T



Reservoir: Mo

Homogeneous evaporation

Melting Points:

Reservoir → Ta 3017 °C

Reservoir → Mo 2623 °C

Melting Points of the compounds:

Li → 1~~80~~.54 °C

2 mA

LiF → 845 °C

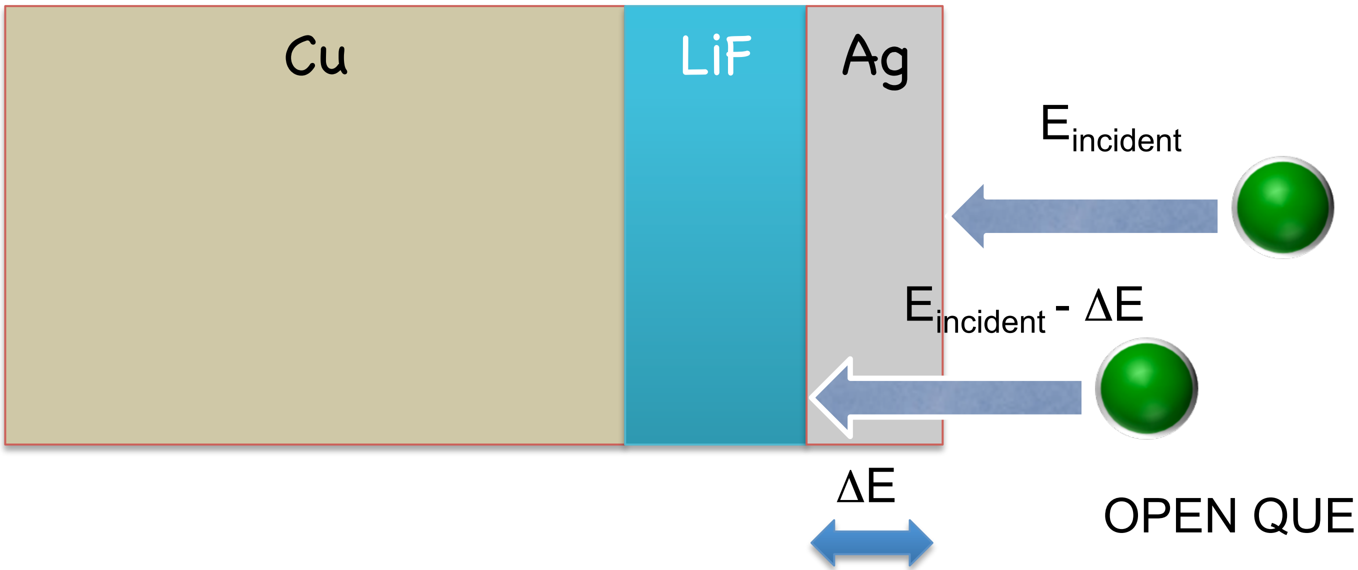
Example:

MgO 2852 °C

Mg 650 °C

Evaporation of a thin layer : Ag or Au.

↳ Protect the preceding thin film



OPEN QUESTION!!!

How much energy will the beam lose?

Is the thin Ag film stable during the experiment?

2 mA

Current status for thermal evaporation

- Thermal Evaporation setup just for evaporate Lithium Fluoride

- Leak tests

- Reassembling

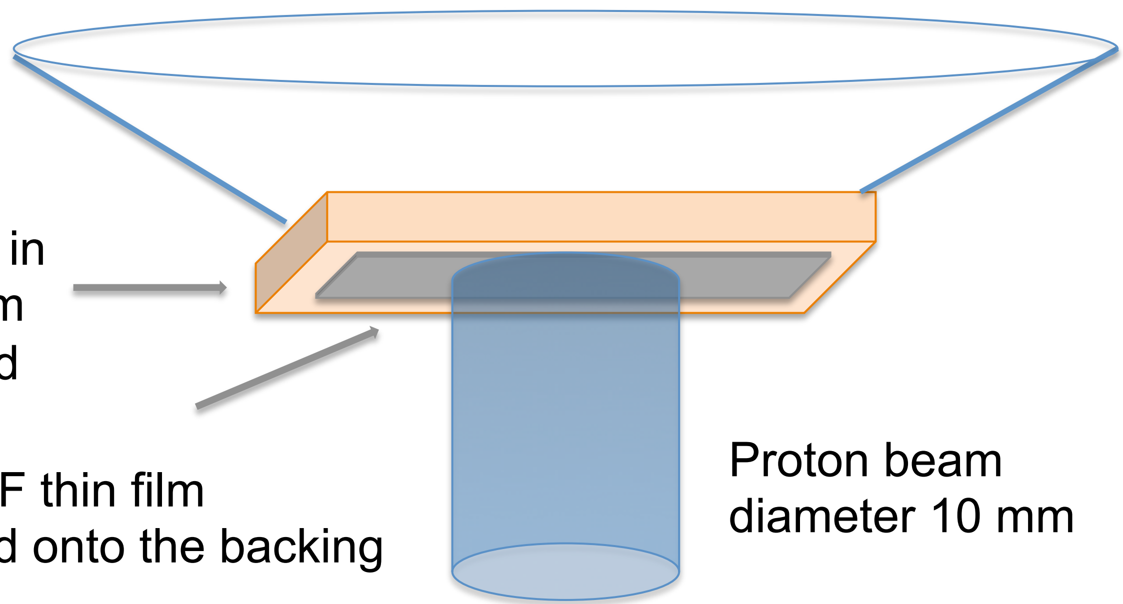
Contents

- Motivation
- Challenges of high power target design
- Thermal Evaporation
- Neutron high power target

Production of quasi-stellar neutron spectra for nuclear astrophysics applications

The principal concept of the high-power neutron target is as follows:

$^{7}Li(p,n)^{7}Be$



D. Petrich et al.NIMA 596 2008.

The neutron production target has to meet the following requirements:

- Surface temperatures have to be kept below 200 ºC to protect the Li layers and to guarantee safe long term operation.

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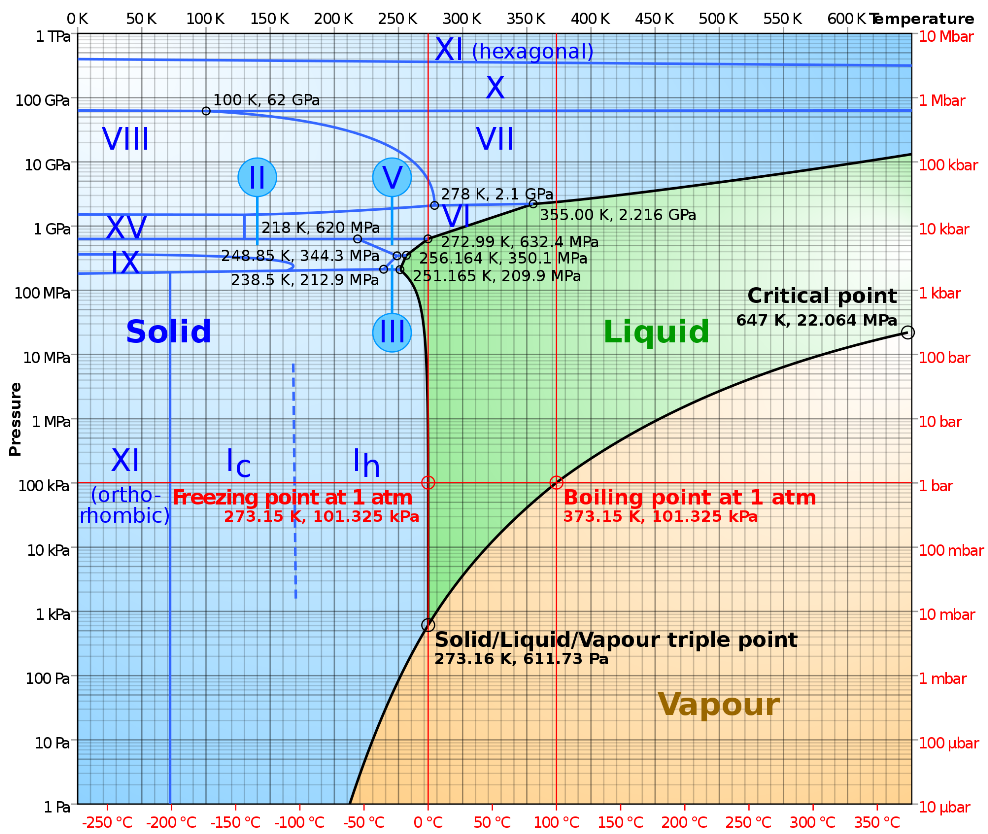
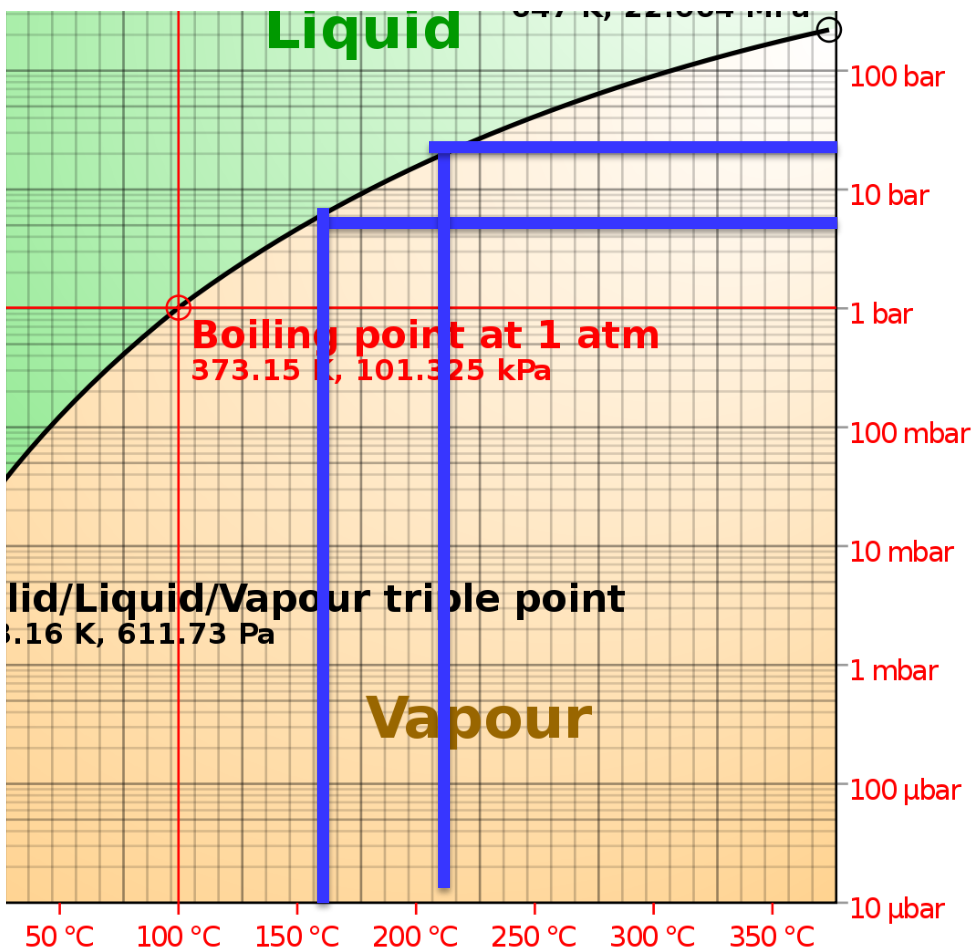


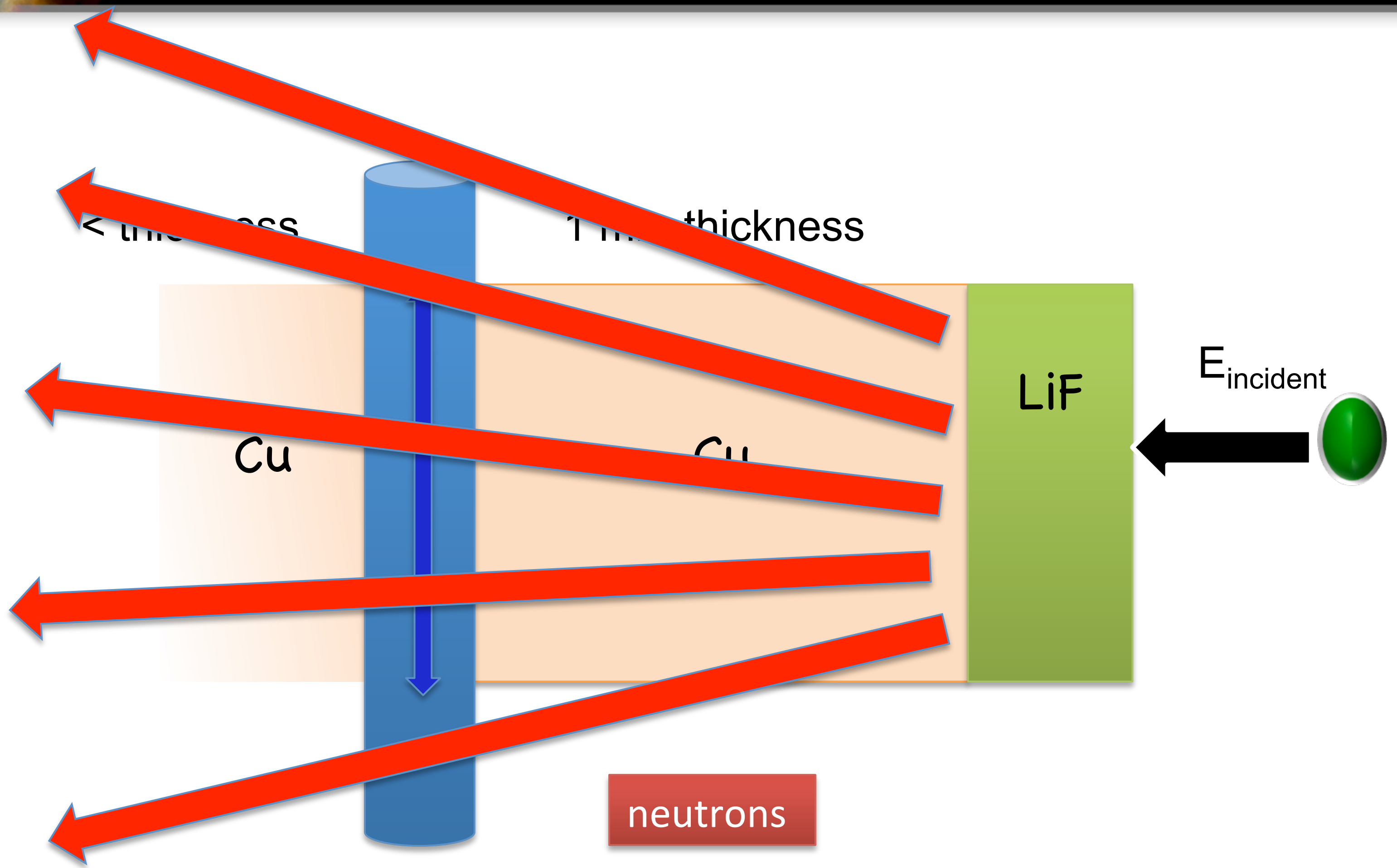
Phase diagram of water

Increase the water pressure of the cooling system.



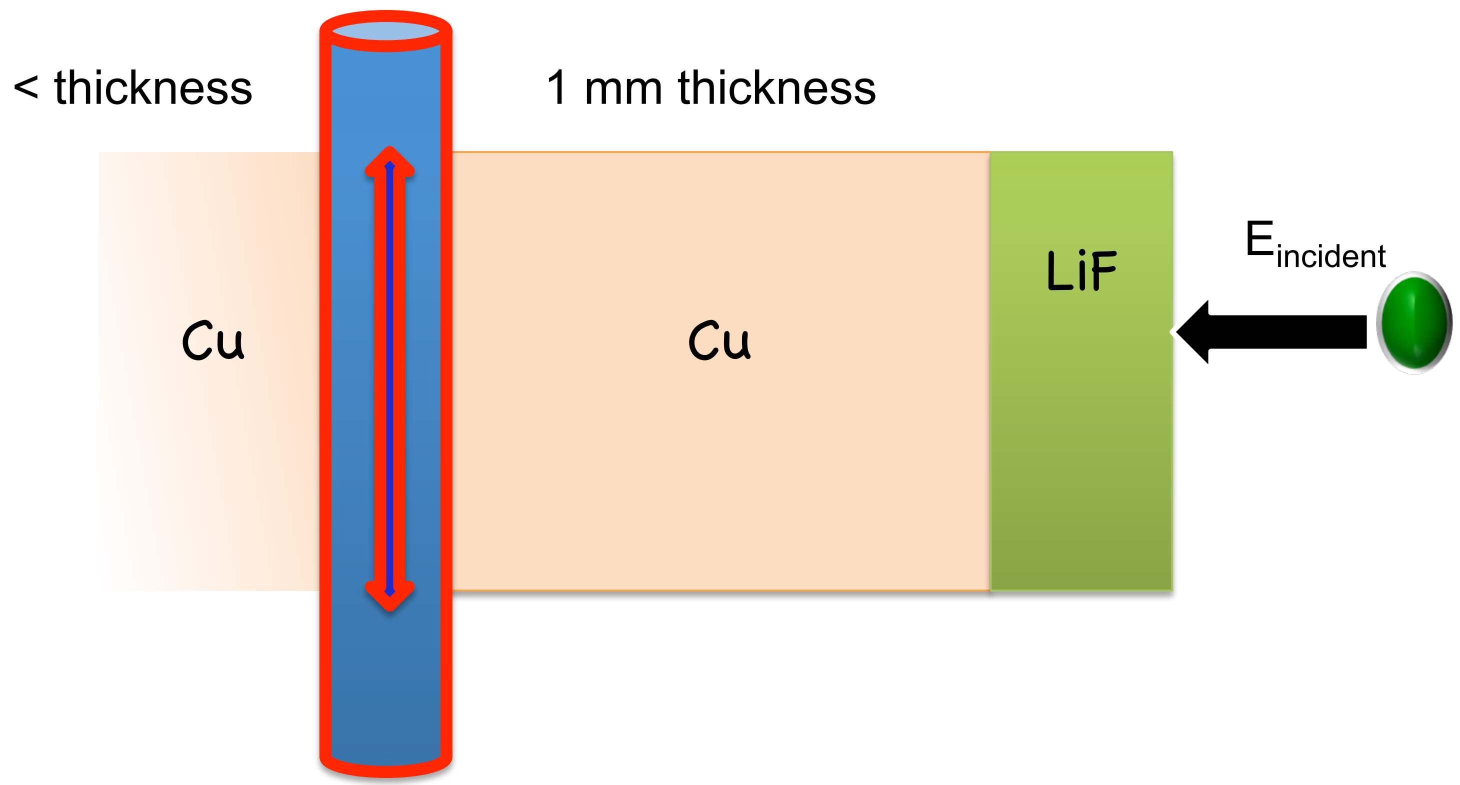
~220 °C

~170 °C


thickness
Cu
LiF
E incident
neutrons

The neutron production target has to meet the following requirements:

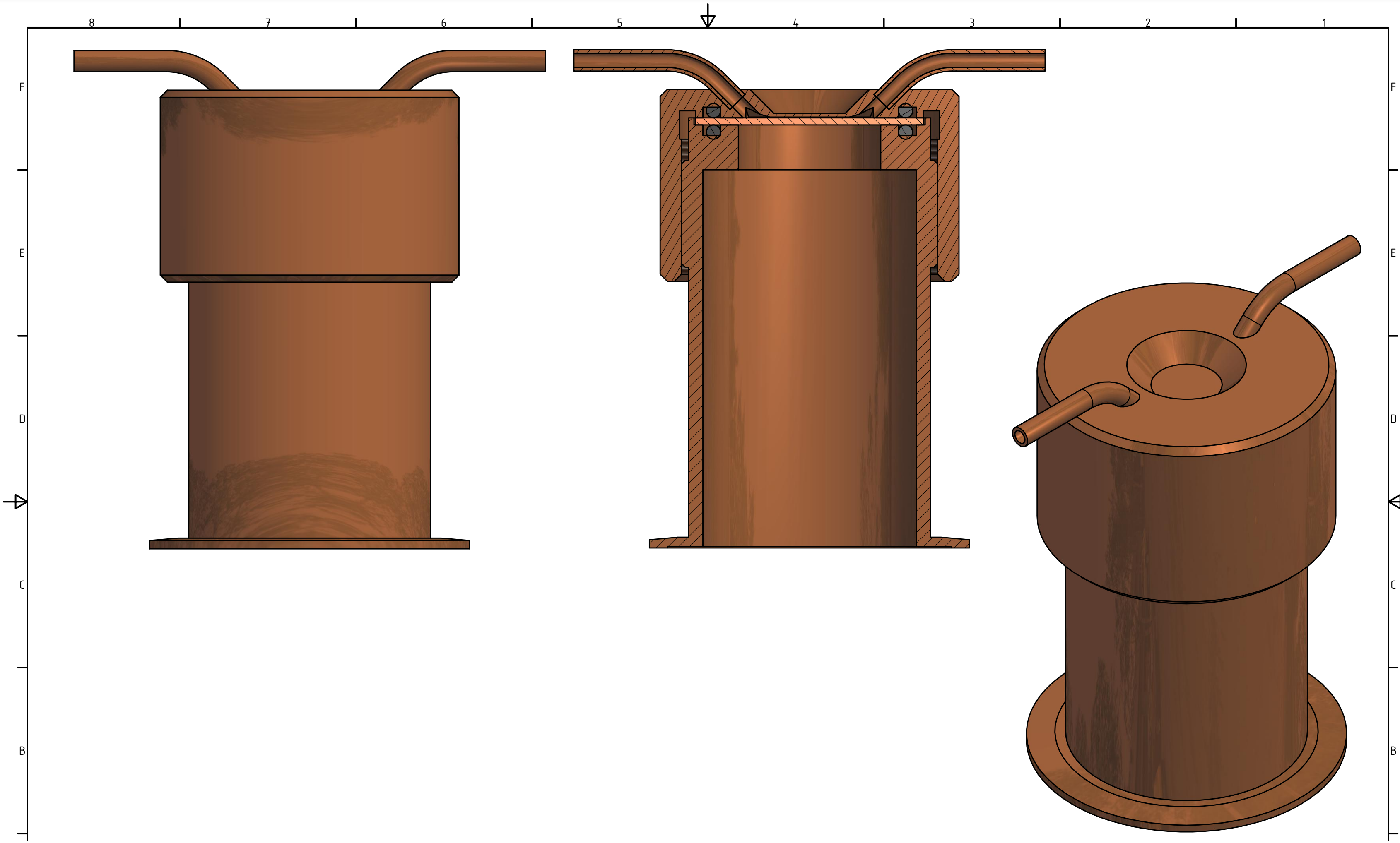
- In forward direction massive parts should be avoided to minimize neutron absorption and scattering
    - Neutrons are emitted in a forward cone of 120º opening angle

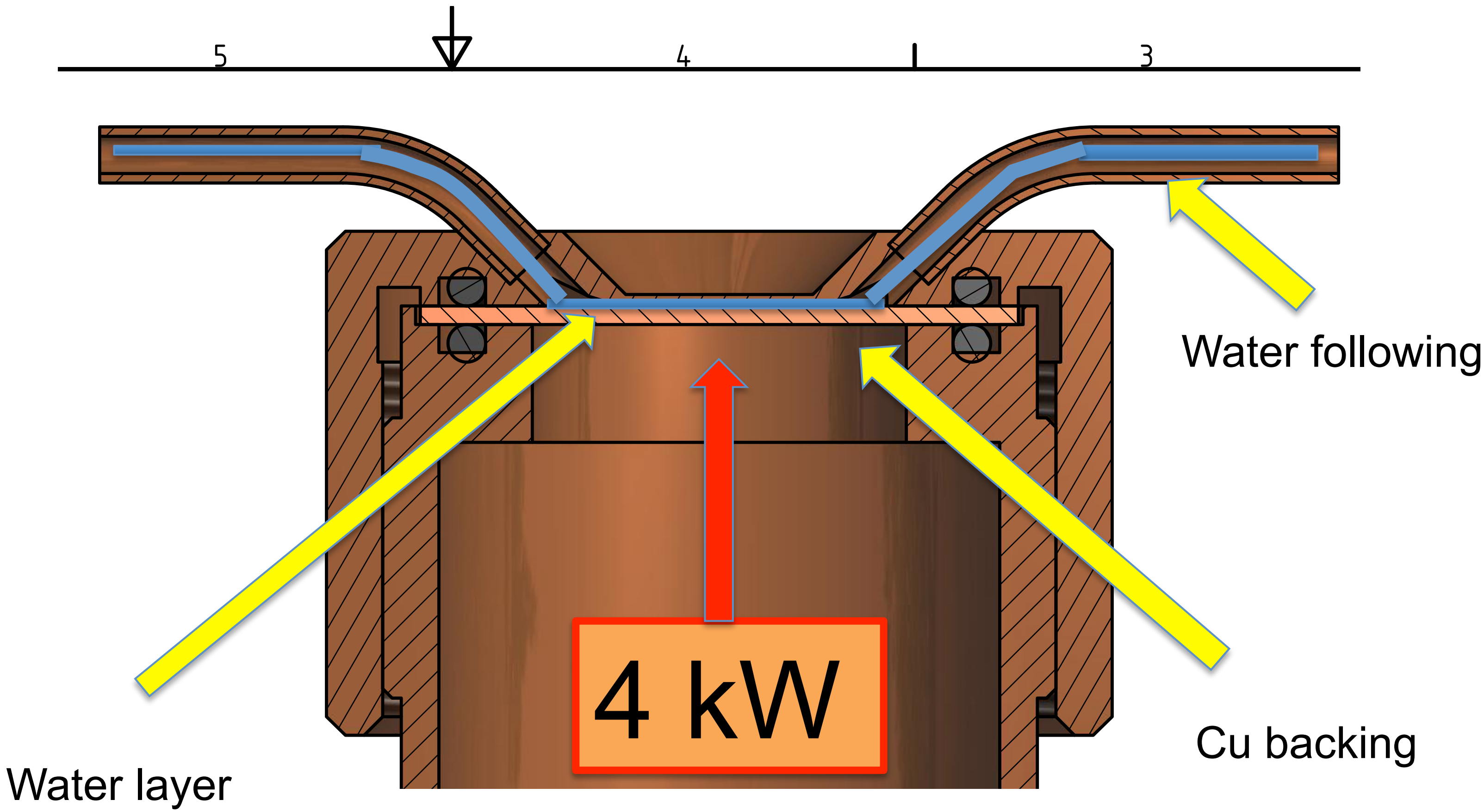

< thickness
1 mm thickness
Cu
Cu
LiF
$E_{incident}$

Since the neutrons will cross the water layer, moderation by the cooling water might be an issue!

Best thickness for the water layer?

Simulations necessary?


8
7
6
5
4
3
2
1
F
E
D
C
B



- prototype: 0.1 mm thickness

symbol	description
$P = 4\,\mathrm{kW}$	power
$c_{\mathrm{H_2O}} = 4.18\,\mathrm{kJ/(kg \cdot K)}$	heat capacity of water
$\rho = 1\,000\,\mathrm{kg/m^3}$	density of water
A	cross section area of water "pipe"
v	water velocity
ΔT	temperature increase

$$\begin{aligned} P &= c_{\mathrm{H_2O}} \cdot \dot{m} \cdot \Delta T \\ &= c_{\mathrm{H_2O}} \cdot \rho \cdot \dot{V} \cdot \Delta T \\ &= c_{\mathrm{H_2O}} \cdot \rho \cdot v \cdot A \cdot \Delta T \end{aligned}$$

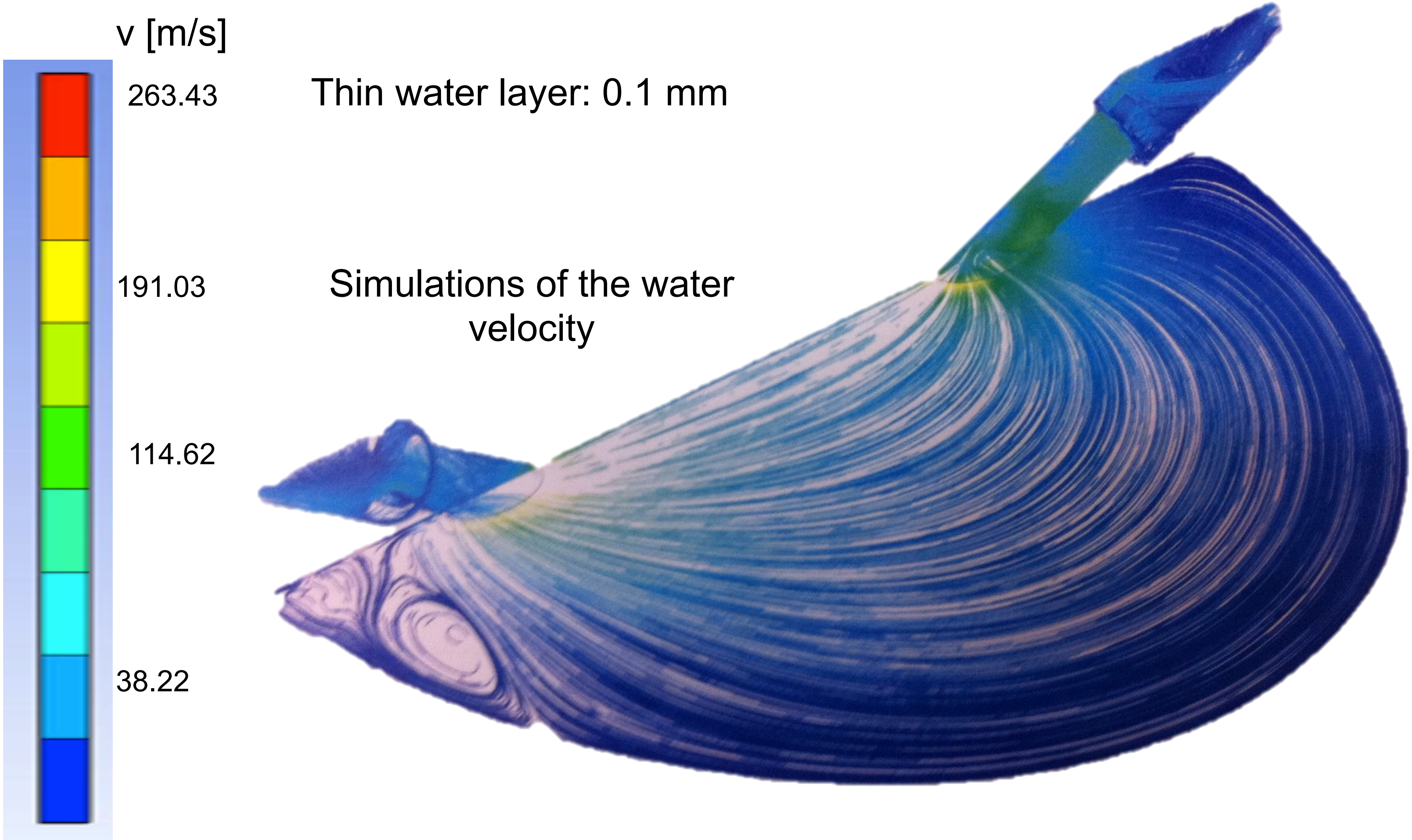
$$\begin{aligned} v \cdot \Delta T &= \frac{P}{c_{\mathrm{H_2O}} \cdot \rho \cdot A} \\ &= \frac{4\,\mathrm{kJ/s}}{4.18\,\mathrm{kJ/(kg \cdot K)} \cdot 1\,000\,\mathrm{kg/m^3} \cdot A} \\ &= \frac{9.57 \cdot 10^{-4}\,\mathrm{K \cdot m^3/s}}{A} \end{aligned}$$

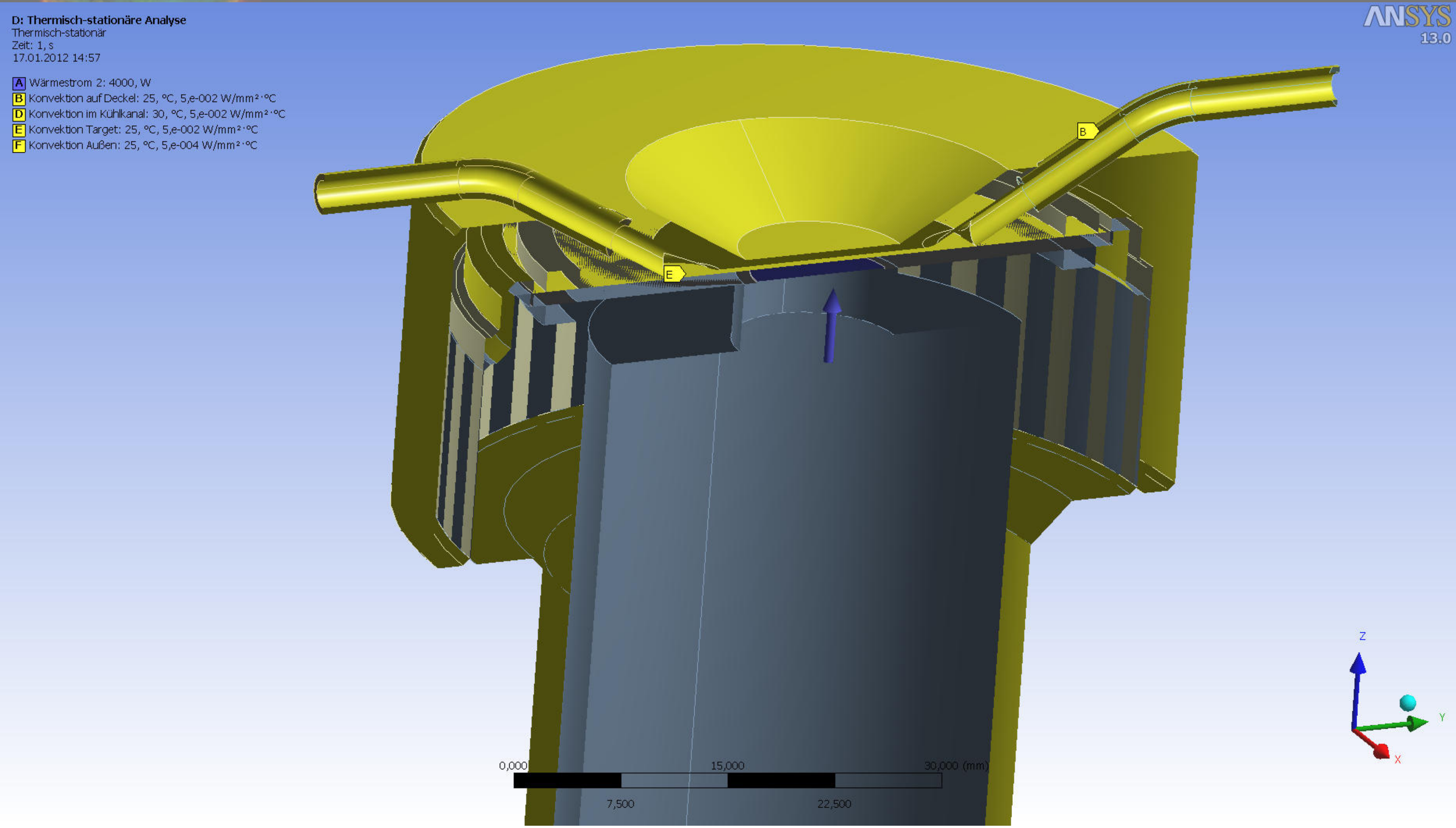
Thin water layer of 0.1 mm

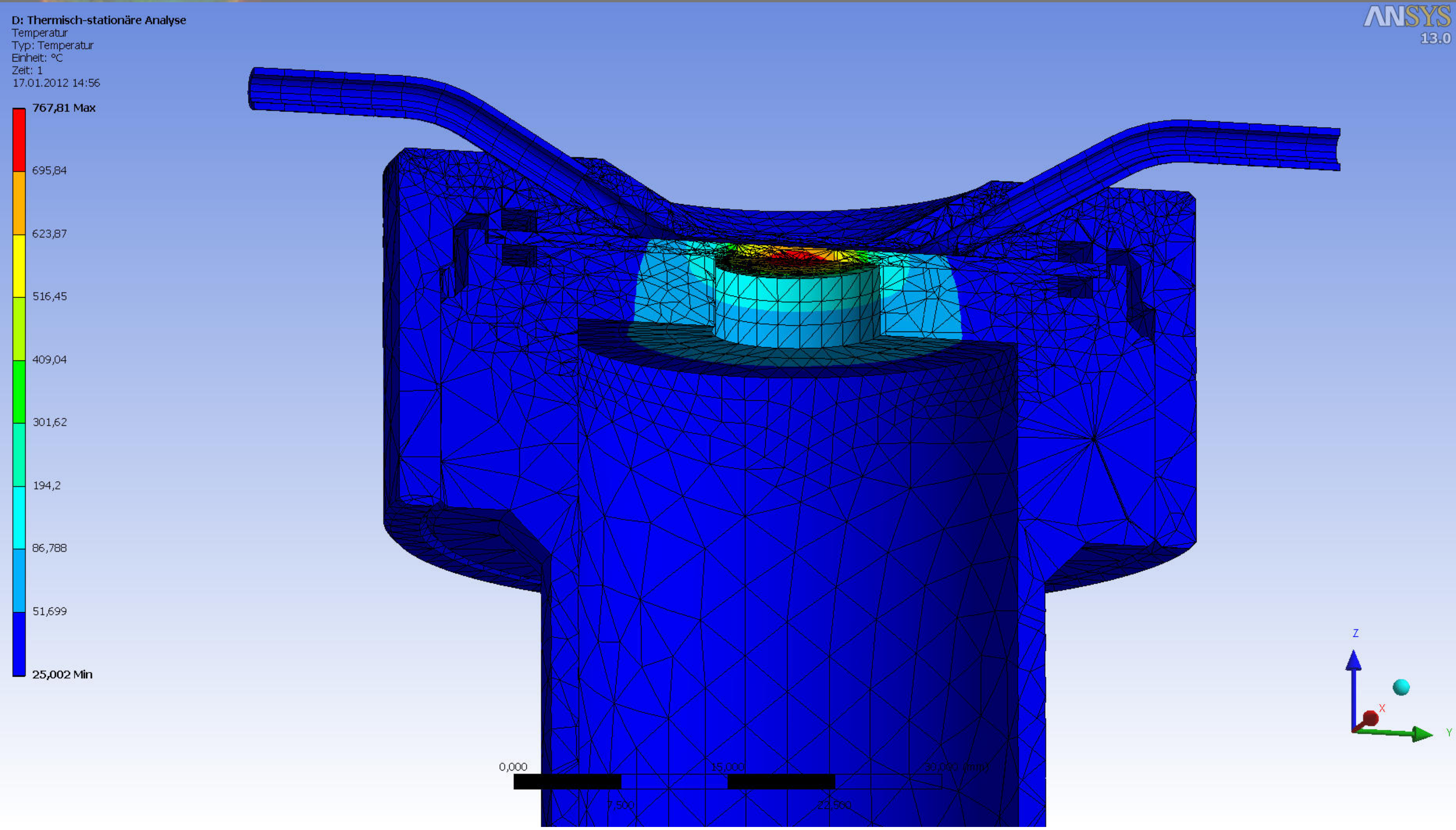
If we want a temperature increase no higher than 100 K, we need water flowing at 9.6 m/s.

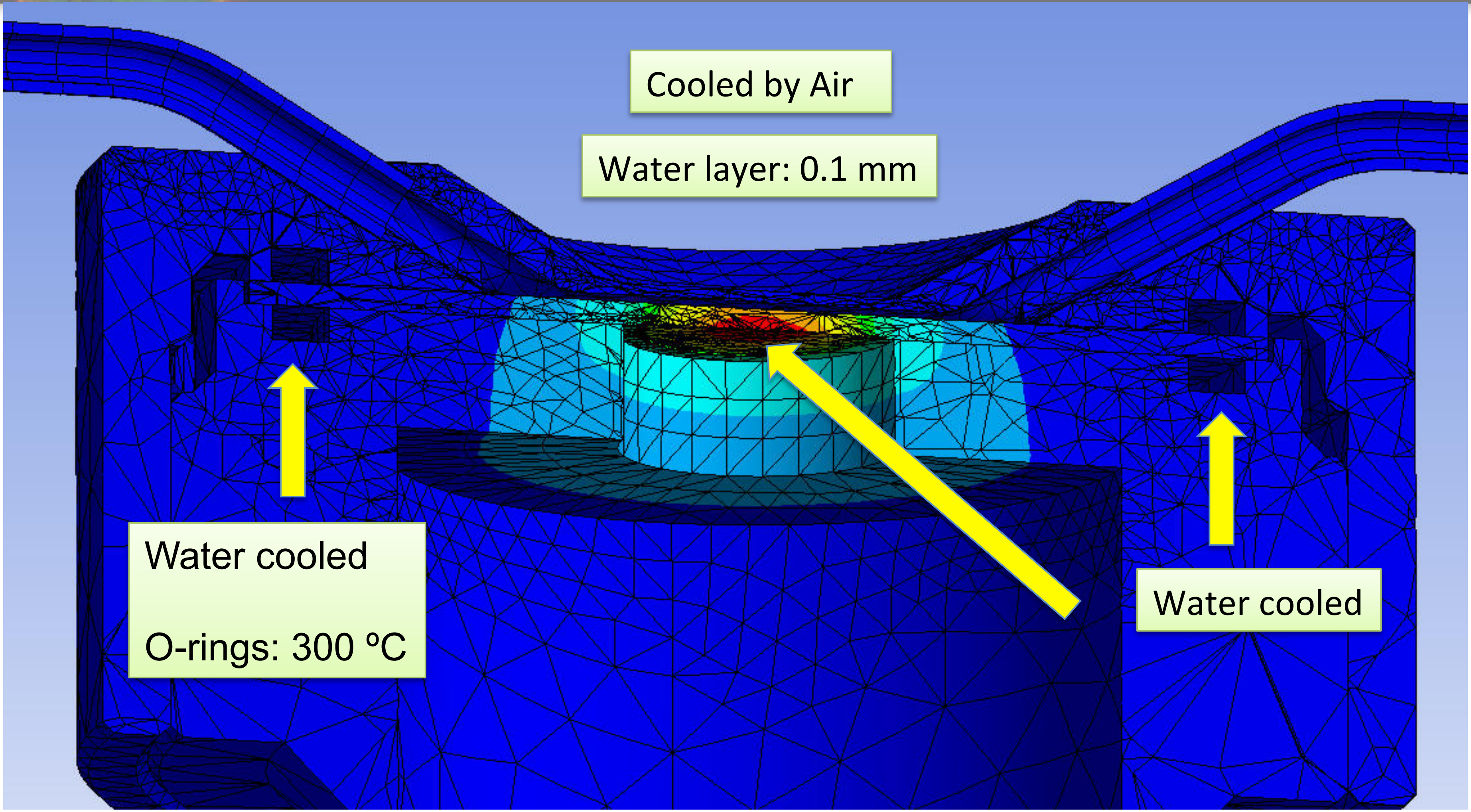
Thin water layer: 0.1 mm

Simulations of the water velocity

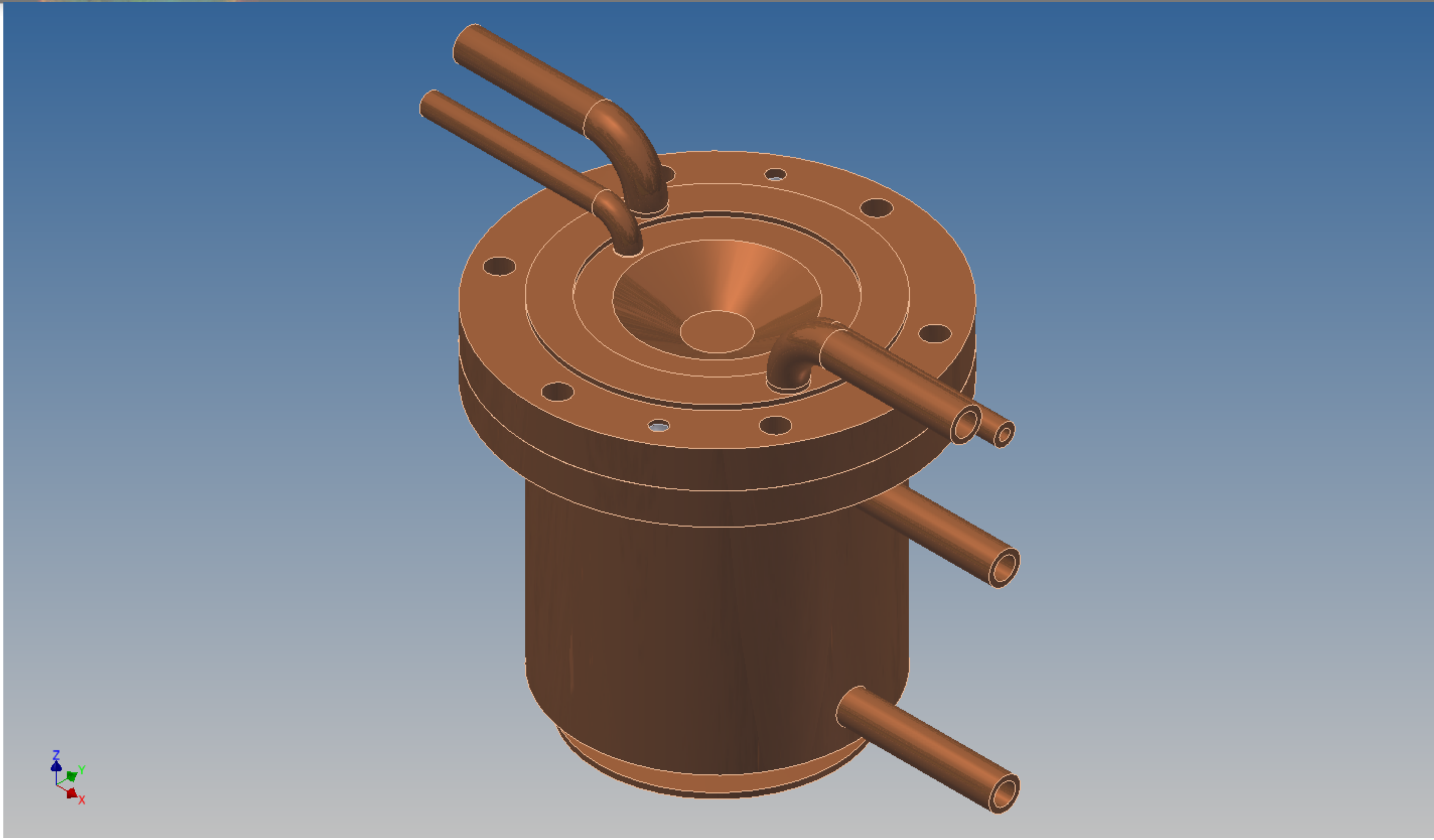


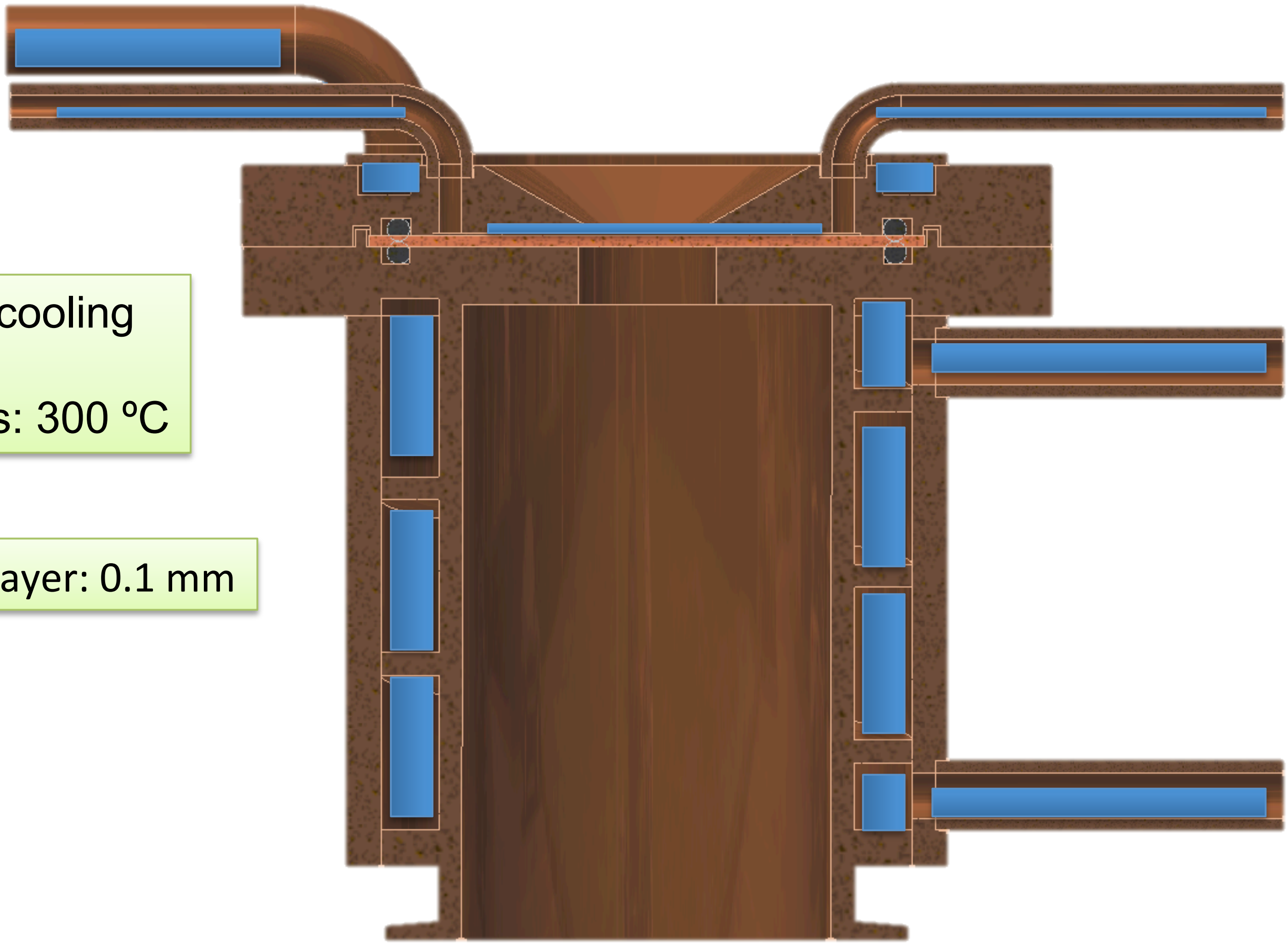

D: Thermisch-stationäre Analyse
Thermisch-stationär
Zeit: 1, s
17.01.2012 14:57
A Wärmestrom 2: 4000, W
B Konvektion auf Deckel: 25, °C, 5,e-002 W/mm²·°C
D Konvektion im Kühlkanal: 30, °C, 5,e-002 W/mm²·°C
E Konvektion Target: 25, °C, 5,e-002 W/mm²·°C
F Konvektion Außen: 25, °C, 5,e-004 W/mm²·°C
ANSYS
13.0
B
E
0,000
15,000
30,000 (mm)
7,500
22,500
Z
Y
X


D: Thermisch-stationäre Analyse
Temperatur
Typ: Temperatur
Einheit: °C
Zeit: 1
17.01.2012 14:56
767,81 Max
695,84
623,87
516,45
409,04
301,62
194,2
86,788
51,699
25,002 Min
ANSYS
13.0
0,000
15,000
30,000 (mm)
7,500
22,500
Z
X
Y


Cooled by Air
Water layer: 0.1 mm
Water cooled
O-rings: 300 ºC
Water cooled


25 ºC
200 ºC
760 ºC


Z
Y
X



Water cooling

O-rings: 300 ºC

Water layer: 0.1 mm

Closed cooling system

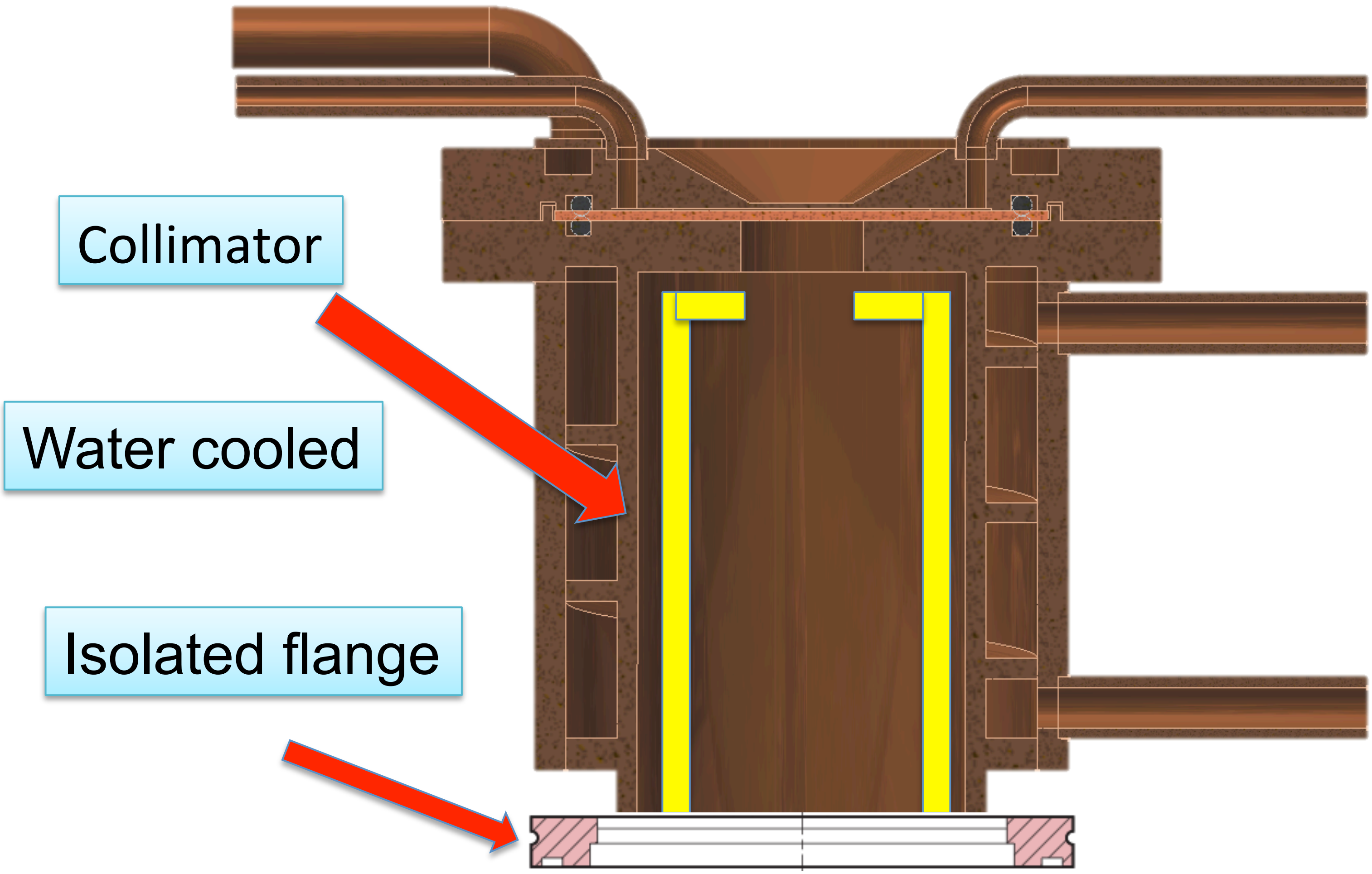
2 mA

Water must be cooled FAST

Efficiency of the pumping system!

Increase the water pressure

Number of protons?



Contents

- Motivation
- Challenges of high power target design
- Thermal Evaporation
- Neutron High Power Target
- Experiment at GSI

GSI, Helmholtzzentrum für Schwerionenforschung GmbH in collaboration with the Super-FRS group.

AIM: to simulate the power of the proton beam

The setup consists of the following equipment provided by Huttinger Elektronik and SensorTherm:

High power generator for induction heating, HF-Generator BIG 20SC. Range up to 22 kW

Pyrometer Series Metis MS09 SensorTherm: Range 350-1800 ºC

and

K type thermocouple working up to 1260 °C

Rod to simulate the beam

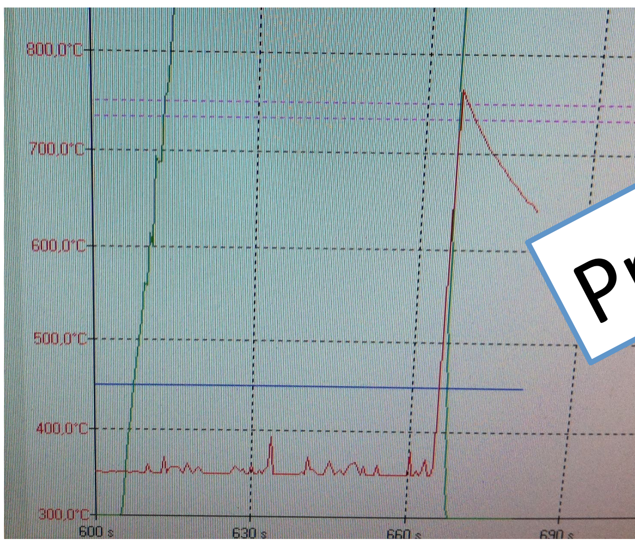
No temperature increase!

Rod to simulate the beam

Stainless steel screw

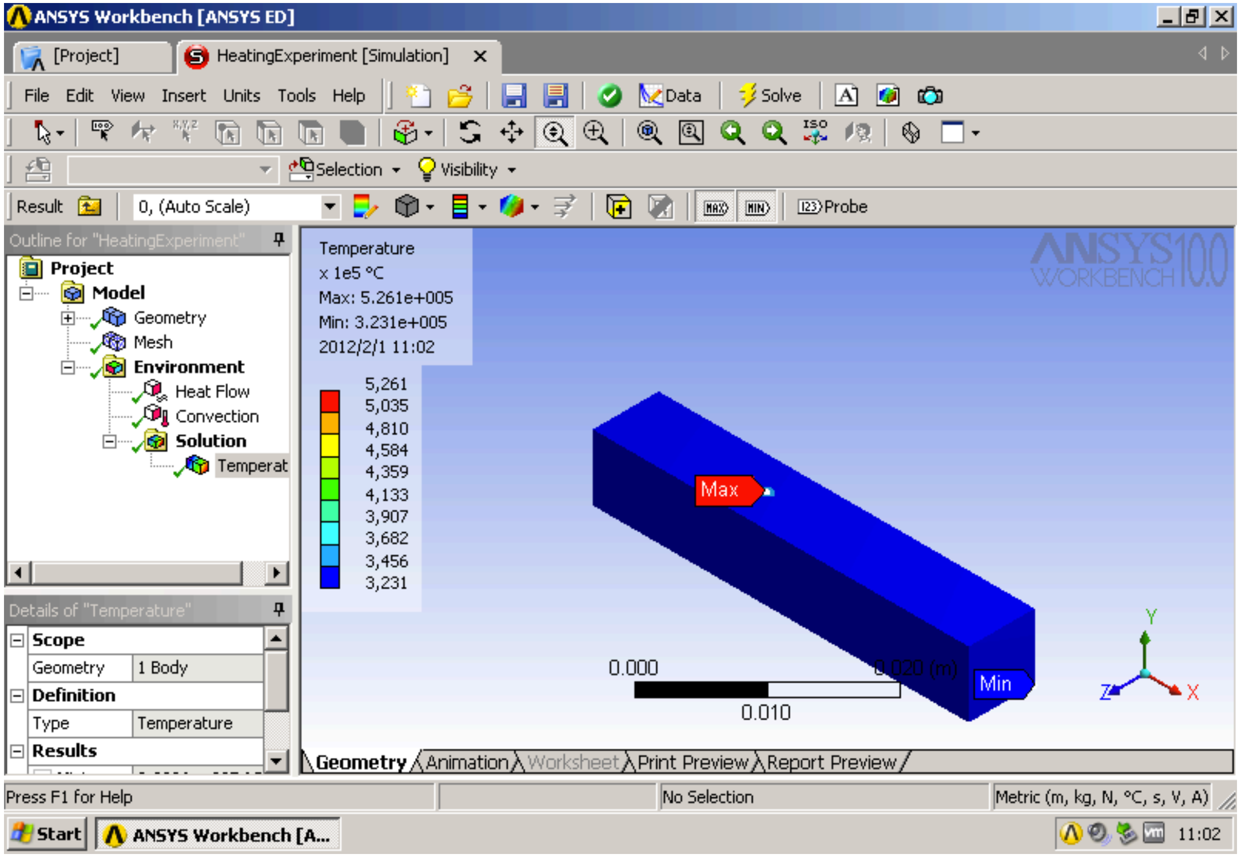
Temperature up to 800 ºC

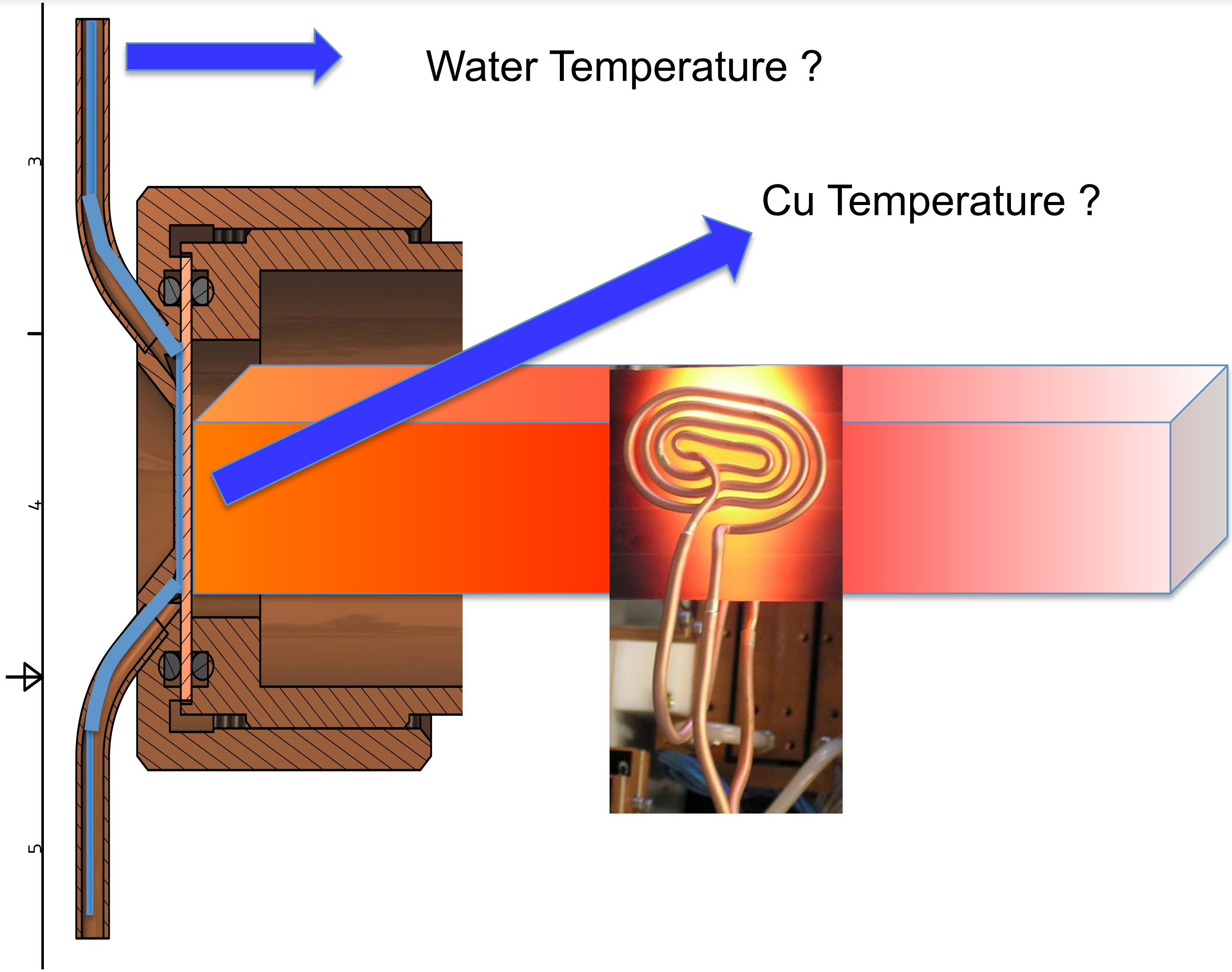
Pyrometer Series Metis MS09
SensorTherm: Range 350-1800 ºC



Preliminary results!

Simulations of the rod: Temperature at the end




Water Temperature ?
Cu Temperature ?
3
4
5

Contents

The principal concept of the high-power target is as follows:

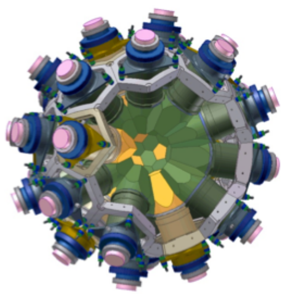
- Backing with 10 mm in diameter and with 1 mm thickness; water-cooled;
- Thin film of the relevant element evaporated onto the backing;

Massive Parts > 1mm

Thickness of the water layer > 0.1mm

Remember:

γ 4π



The technical challenges for targets in high-power proton beams are:

- The same as for the neutron high power target
- The background from backing impurities should be as low as possible
- The target and the cooling configuration need to fit into 4π BaF_2 detector
- The targets should be easy to handle

Backing material?

Material	Thermal conductivity W/mK
Aluminium	237
Gold	318
Copper	401
Chemical Vapor Deposition (CVD) diamond	2000

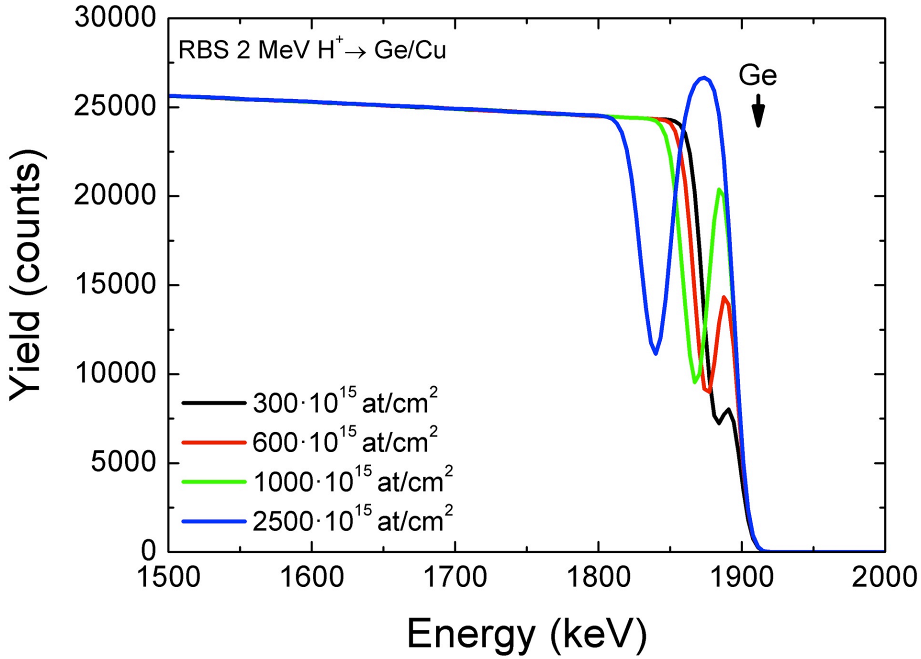
Another Advantage of CVD

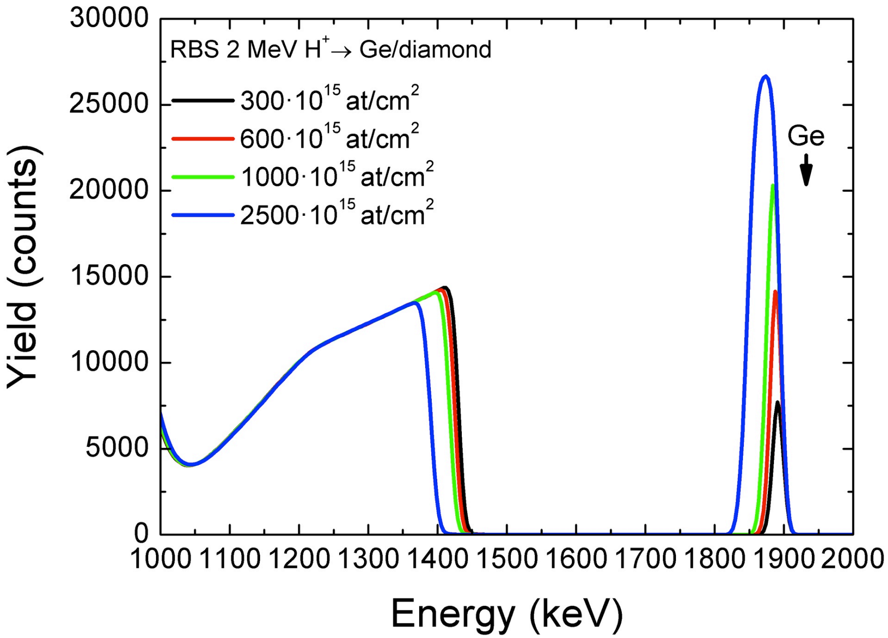
If it is necessary to perform measurements for:

Target thickness,
Stoichiometry,
Homogeneity,
Check the stability under bombardment

For example:
Ion beam Techniques: Rutherford Backscattering Spectroscopy (RBS)

RBS simulation: SIMNRA





SIMNRA by Matej Mayer 6.0

Summary and Outlook

→ Prototype in developing phase.

→ Experiment at GSI will enable to validate the simulations.

Final prototype

Test with proton beam. Different range of currents

Experiments to measure the layer of LiF after the bombardment.
Degradation may occur! Not stable!
Ion beam Techniques: RBS, PIGE

Summary and Outlook

With the Knowledge of the Neutron High Power Target

↓

It is possible to produce a Proton High Power Target

Future exciting experiments are needed to be performed in order to achieve a stable target

THANK YOU FOR YOUR ATTENTION !!!

Goethe Universität Frankfurt

- Experimental Astrophysics Group:

Reifarth, R.; Sonnabend, K.; Plag, R.; Meusel, O.; Schmidt, S.; Altstadt, S.; Brost, K.; Ershova, O.;

Beinrucker, C.; Glorius, J.; Göbel, K.; Heftrich, T.; Koloczek, A.; Kräckmann, S.; Langer, C.;

Landwehr, K.; Mikorski, M.; Pohl, M.; Rastrepina, A.; Ritter, C.; Schleyer, C. Slavkovská, Z.;

Thomas, T. Gilbert, M.; Volknandt, M.; Weigand, M.

- Thomas Metz: inventor drawings

GSI, Helmholtzzentrum für Schwerionenforschung GmbH

Dermati, K.; Wischert, I.; Heil. M;