PREX2-CREX Target

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1 Oct 2017

PREX2/CREX Collaboration Meeting

Target Chamber Overview

(as presented to the ERR committee on 17 May 2017)

- The target chamber will be Al made with 0.25” walls, 60.96 cm diameter and 33 cm long along the beam line
- 2 independent linear motion mechanisms on bellows, one cryogenic (for ^{208}Pb and ^{48}Ca targets with 18 positions, stroke 76.25 cm) and one water cooled (for dummies + water cell with 6 positions, stroke of 33 cm)
- The motion mechanisms are outside vacuum and serviceable without breaking vacuum
- Cu made cryogenic ladder will support 12 Pb targets (10 high purity ^{208}Pb, 2 regular Pb), 2 Ca targets and 3 C targets
- All vacuum seals on the target chamber will be metal made

List of Targets

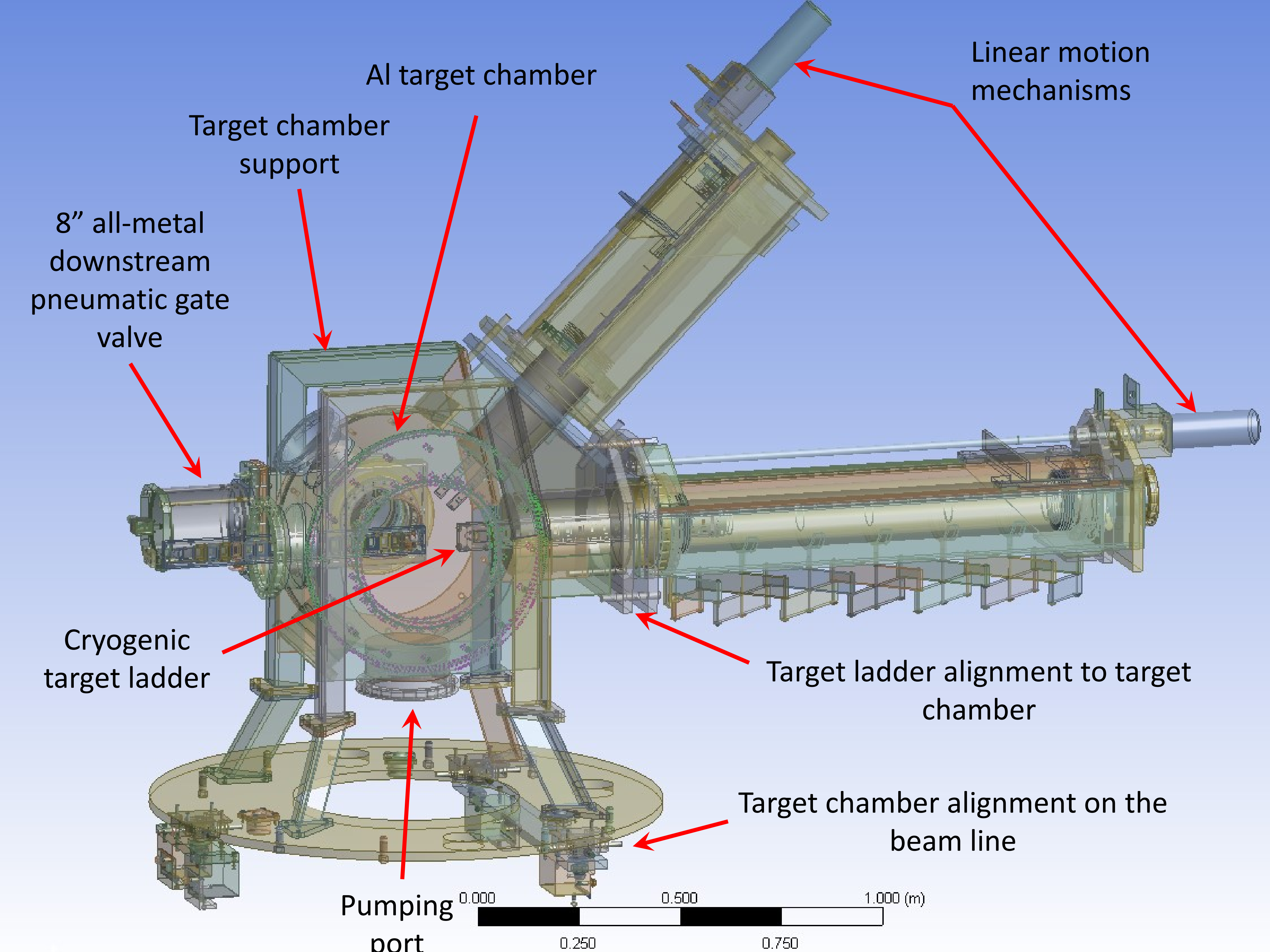
Water cooled

Optics Ladder	
Carbon Hole	~0.1 g/cm^2
Watercell	
Thin C foil	0.1 g/cm^2
Thin natural Pb	0.05 g/cm^2
Thin ^{40}Ca	0.05 g/cm^2

Cryogenically cooled

Production Ladder	
Carbon hole	~0.1 g/cm^2
(9x) ^{208}Pb/diamond	0.5/0.25 mm
^{208}Pb/graphite	0.5/0.25 mm
^{48}Ca (tilted)	1 g/cm^2
^{40}Ca	1 g/cm^2
thick C	0.5 g/cm^2
Pb/diamond	0.5 mm
Pb/graphite	0.5 mm

- The Pb target is low power, less than 100 W at 70 μA and the Ca target is high power, less than 400 W at 150 μA
- Coolant: 15 K – 12 atm He gas from ESR
- 2 beam line gate valves and a purge system will protect the Ca target against a beam line vacuum break

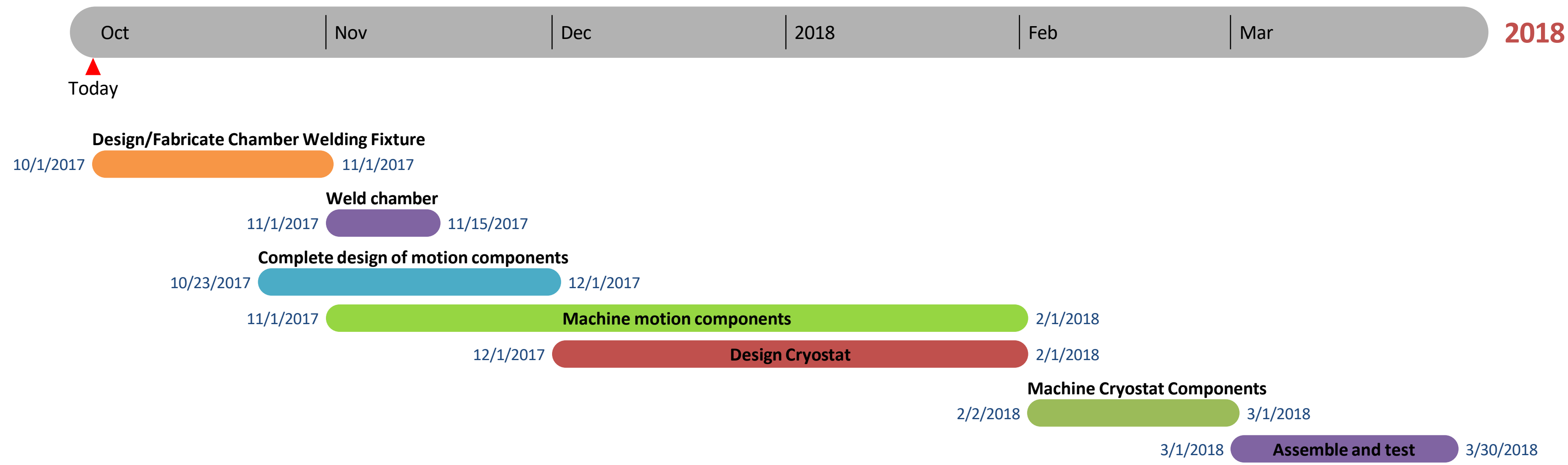

Linear motion mechanisms
Al target chamber
Target chamber support
8” all-metal downstream pneumatic gate valve
Cryogenic target ladder
Target ladder alignment to target chamber
Target chamber alignment on the beam line
Pumping port
0.000
0.500
1.000 (m)
0.250
0.750

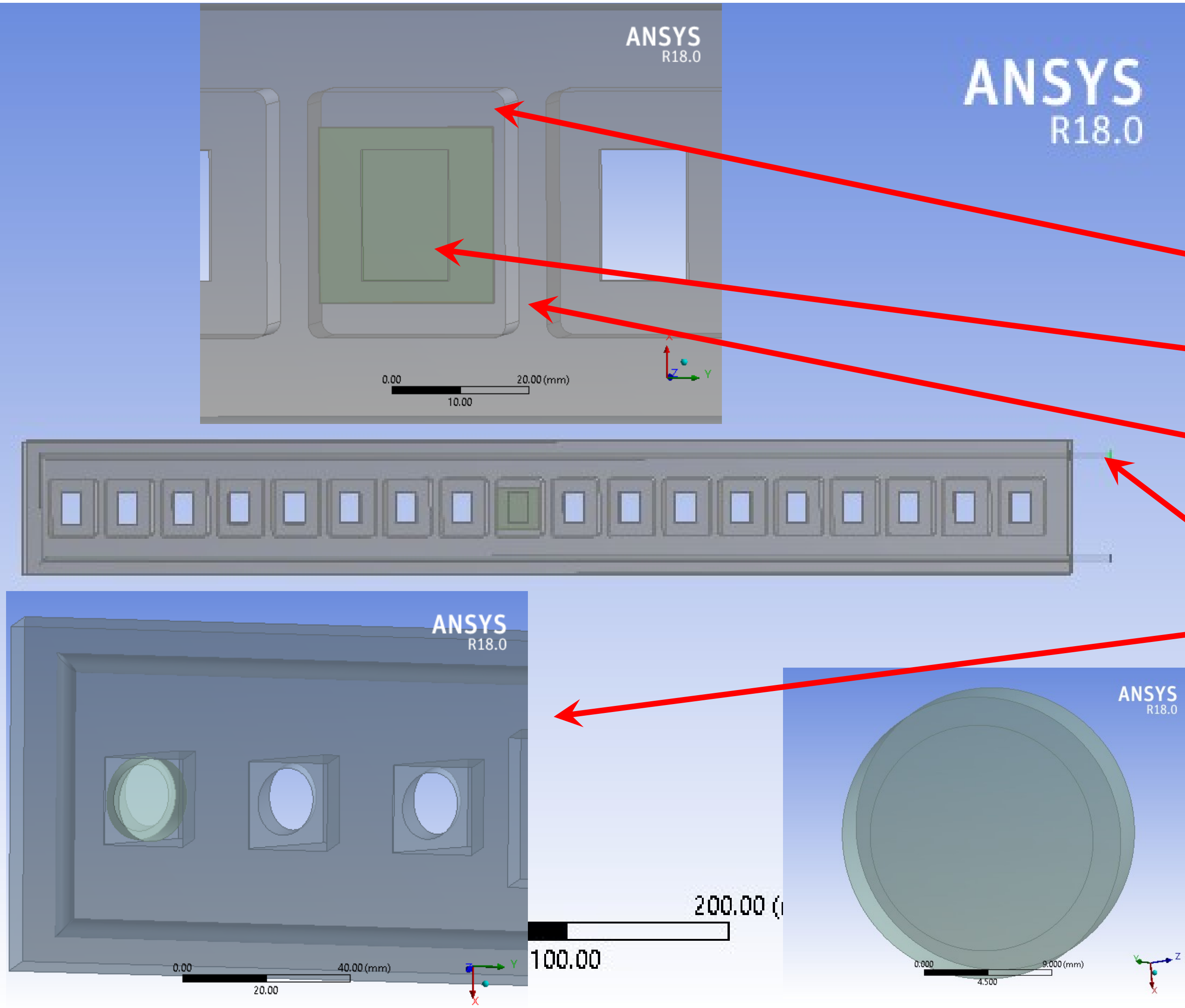
Target System

Subsystem	Cost ($)	Status / Completion date
Scattering chamber	51,000	Almost complete / spring 2018
Vacuum system	60,000	Procurement only / 2018
Cold target ladder	47,500	Design almost complete / spring 2018
Warm target ladder	30,500	Design almost complete / spring 2018
Transfer can+lines	29,500	Design needed / 2018
Alignment system	10,000	Mounts / 2018
Instrumentation	57,500	Thermometry+Software / 2018
TOTAL	286,000	

- Scattering chamber + Cold + Warm target ladders + some instrumentation by CFDFAC (only if done by May 2018), rest by Hall A/JLab
- 2-stage alignment adjusters could position a target on the beam line within 1 mm (the cold/warm ladders will be aligned on the bench to fiducials on the chamber wall, the chamber will then be aligned in the hall on the beam line)
- The ^{208}Pb targets will be loaded on the bench in the Cu frame, the ^{48}Ca target will be installed in the hall in the Cu frame

PREX/CREX TARGET SCHEDULE
(courtesy of Dave Meekins)



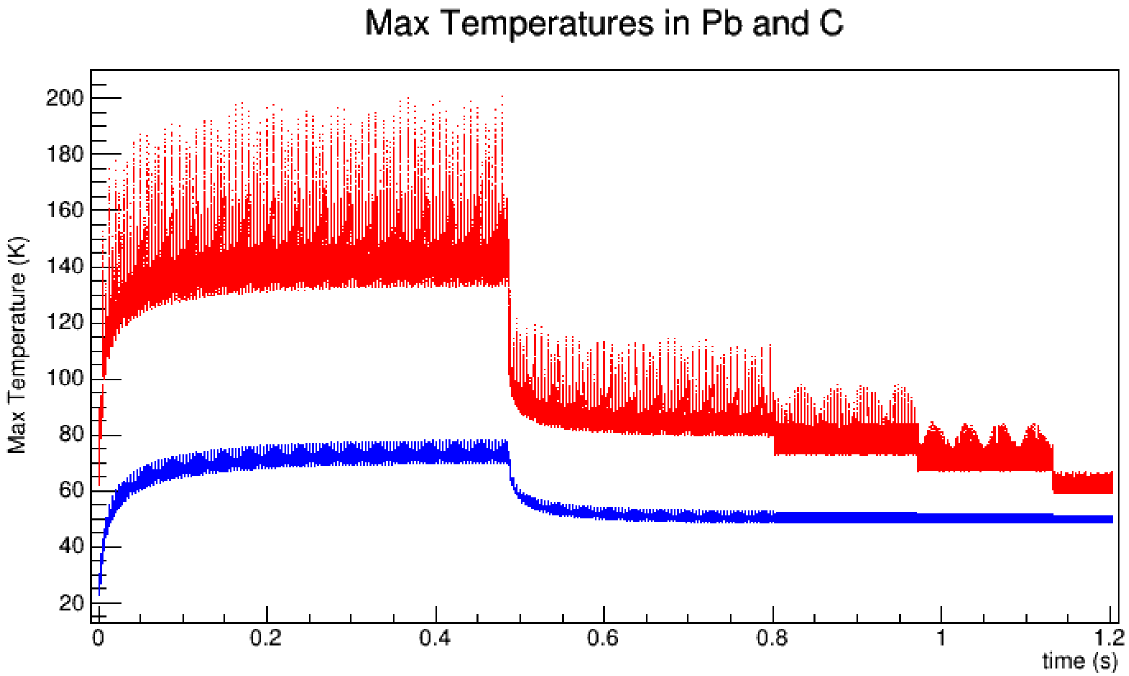


- 18 positions cryogenic prex target ladder
- Ladder length 654.05 mm, width 82.55 mm, depth 19.05 mm (Cu-made)
- Pb target "housing" height 35.8 mm, width28.8 mm
- Pb target "beam face" height 19.05 mm, width 12.7 mm
- Distance between adjacent Pb targets housings 6 mm
- Coolant channel diameter 4.57 mm
- Reserved 3 Ca loading positions
- Ca puck diameter 20 mm, thickness 5 mm, beam face diameter 16 mm, tilted 45 deg to beam axis

CFDFAC: Transient CFD model

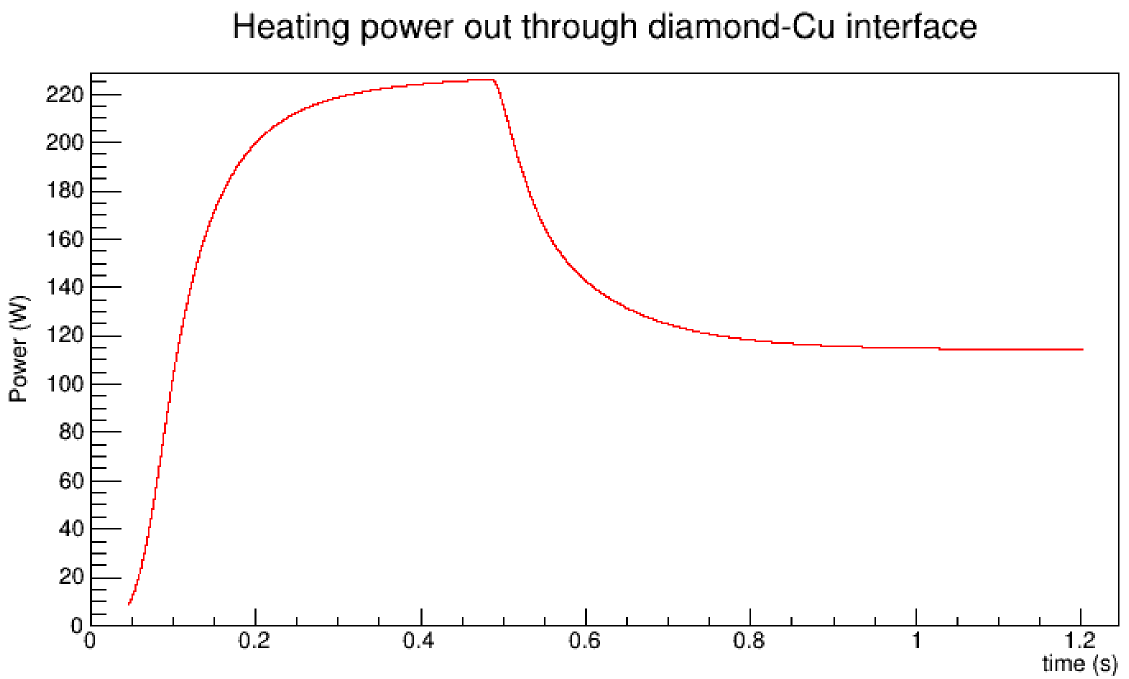
- In response to a question from a ERR-2016 committee member: will cryo-cooling yield a temperature bump as diamond becomes a thermal insulator at low T?
- Transient CFD model ran on a sandwich 250 µm-500 µm-250 µm C-Pb-C (diamond)
- Thermal contact C – Cu frame on only one side of the sandwich, contact area 4 cm^2, considered ideal contact and diamond was assumed undegraded
- Diamond, Pb, Cu properties considered temperature dependent, taken from MPDB
- Coolant considered to be liquid He (LHe), inlet at 4.8 K, 2 atm, 10 g/s, constant properties
- Beam raster size 4x4 mm^2, intrinsic beam spot considered of size 160 µm
- Beam raster frequencies (f_x, f_y) ~25 kHz with $\Delta f = |f_x - f_y|$ = 120 Hz, 240 Hz and 480 Hz respectively, the intrinsic beam spot is painted on the target sandwich with the raster frequencies
- The beam power deposition densities considered were for 140 µA and 70 µA respectively (nominal beam current proposed for prex2 is 70 µA)
- Time step for the simulation 2.11 µs, beam raster period is ~ 40 µs

- The beam is considered full power starting at t = 0 s



Upper plot:

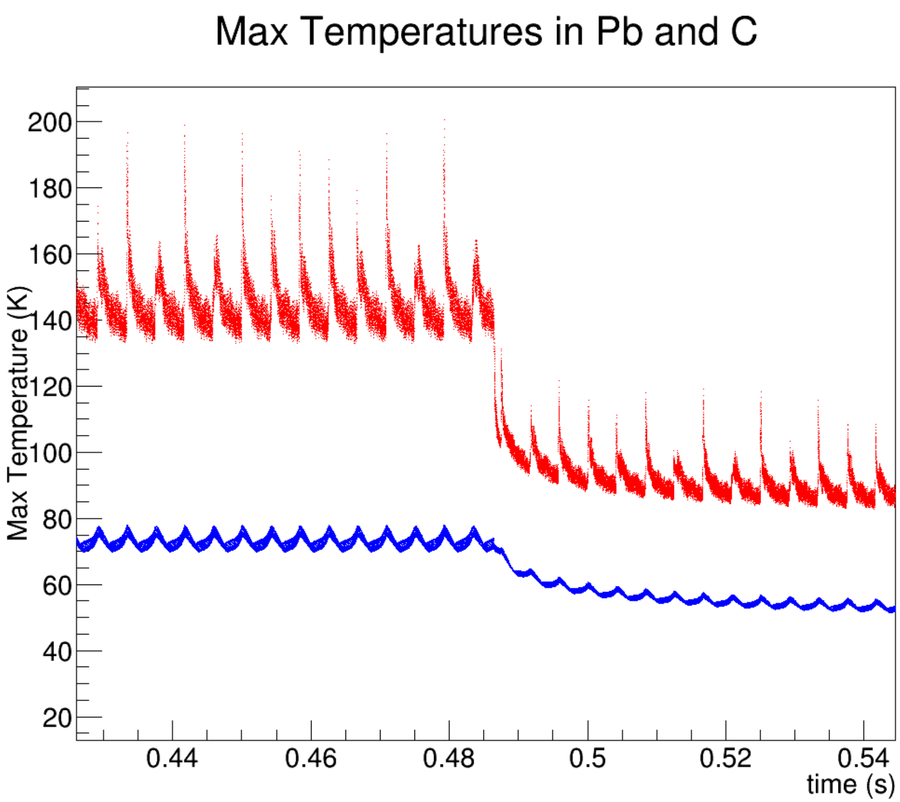
max temperature in Pb and diamond (C) vs. time at 140 μA, at 70 μA, fx – fy = 120 Hz, 240 Hz, 480 Hz and doubling of beam spot size

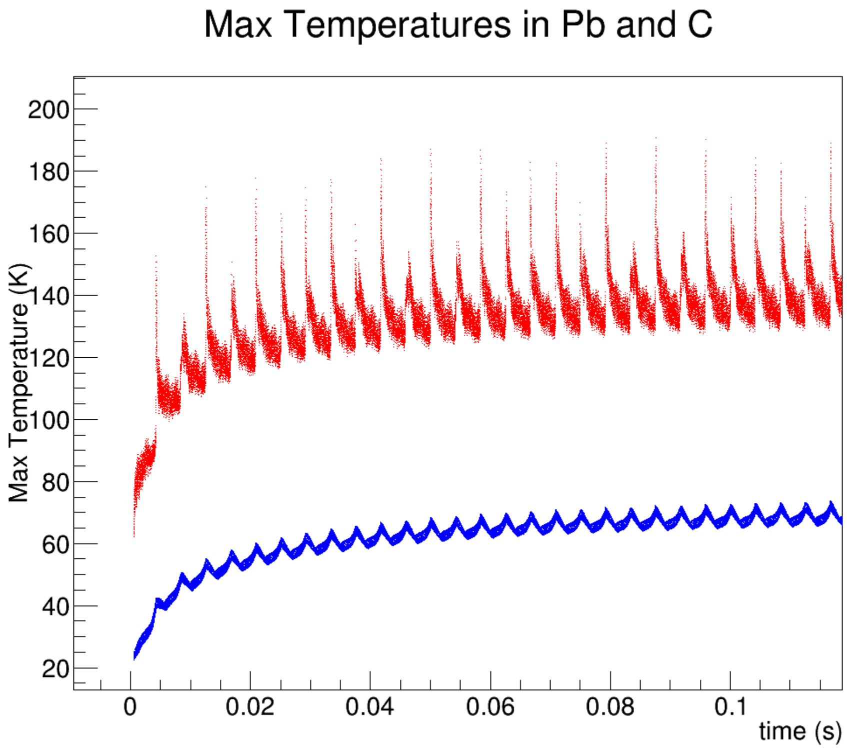


Lower plot:

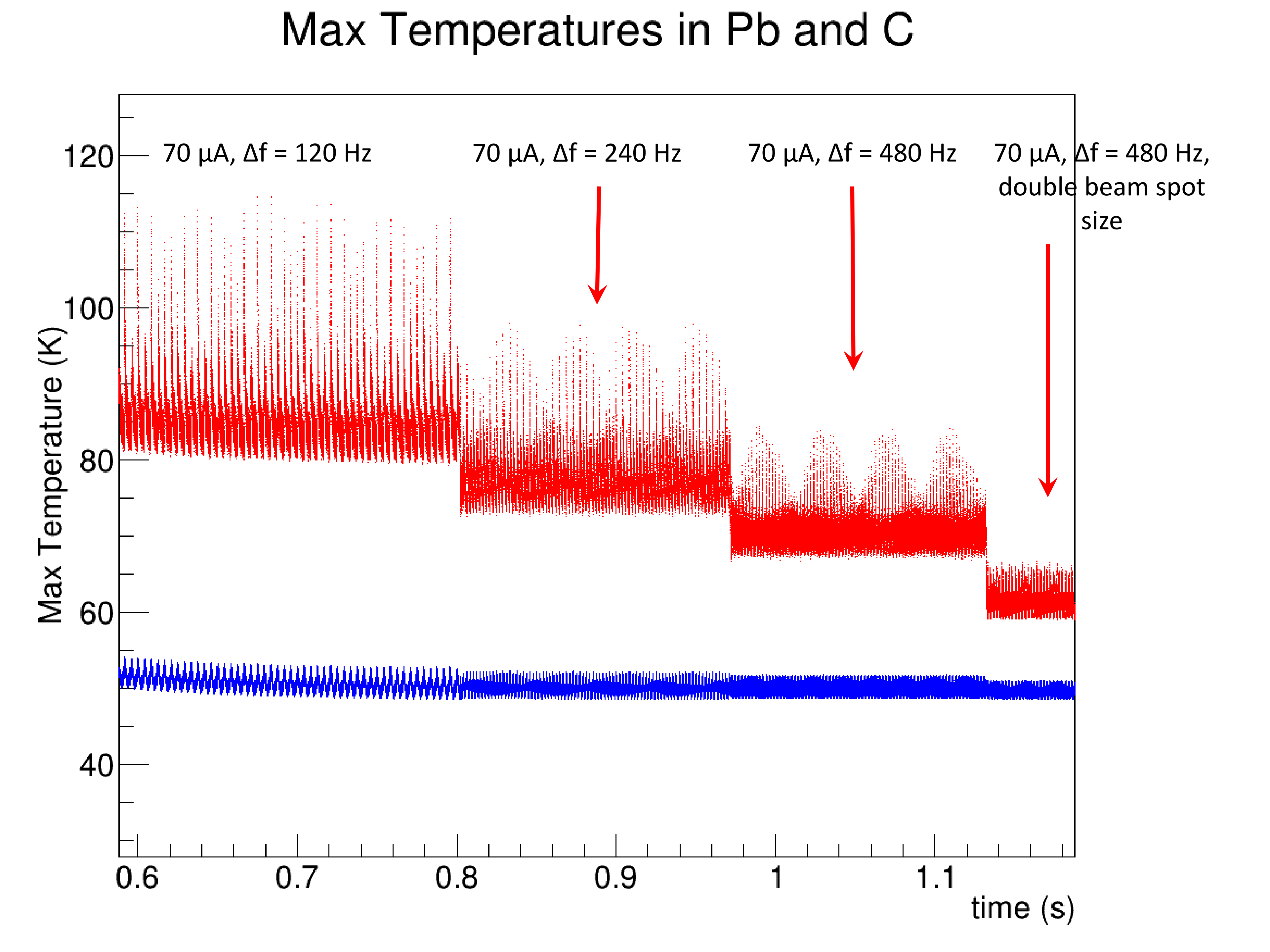
power out through C-Cu interface at 140 μA and 70 μA beam current

Transition from 140 μA to 70 μA
for fx = 25080 Hz, fy = 24960 Hz)
or Δf = fx – fy = 120 Hz





No temperature "bump" observed at 140 μA for (25080 Hz, 24960 Hz) or Δf = 120 Hz, when the beam is turned "ON"



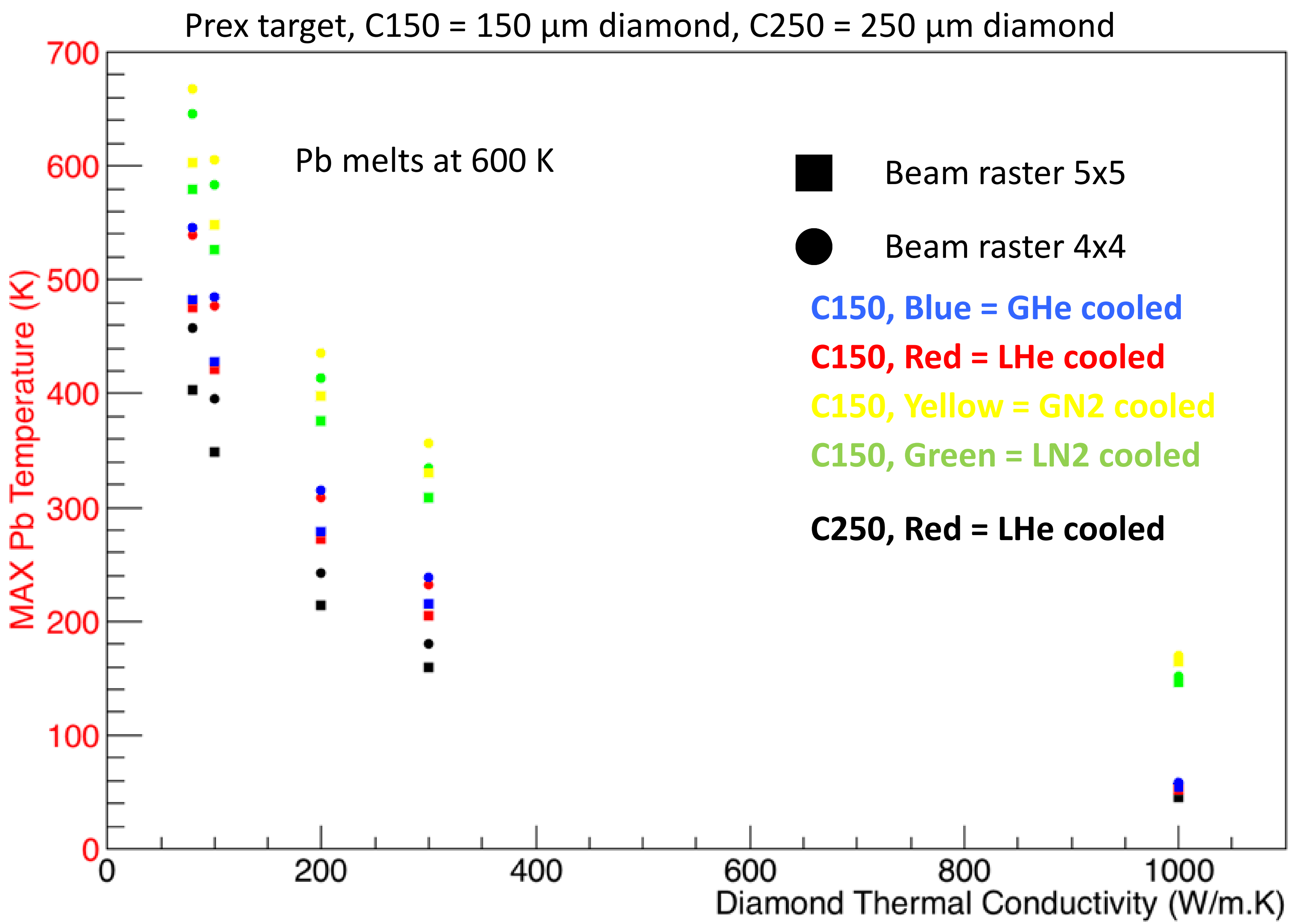
Max Temperatures in Pb and C
70 µA, Δf = 120 Hz
70 µA, Δf = 240 Hz
70 µA, Δf = 480 Hz
70 µA, Δf = 480 Hz, double beam spot size
Max Temperature (K)
120
100
80
60
40
0.6
0.7
0.8
0.9
1
1.1
time (s)

CFDFAC: Pb Thermal Analysis

- In response to a question raised by an ERR-2016 committee member: consider LN2 as coolant to see if it lowers the max T in Pb compared to cold He
- The assessment to be done considering the prex2 cold ladder with 18 positions, one loaded with a sandwich diamond-Pb-diamond, where two diamond thicknesses will be considered, 150 μm and 250 μm
- Four coolant choices to be considered: LHe inlet at 10 g/s, 4.8 K, 2 atm; GHe inlet at 10 g/s, 15 K, 10 atm; LN2 inlet at 2 g/s, 77 K, 1 atm and GN2 inlet at 2 g/s, 78 K, 1 atm
- 2 beam raster sizes to be considered: 4x4 mm^2 and 5x5 mm^2, total heating power deposited in 150-500-150 sandwich 82 W@70 μA, total heating power deposited in 250-500-250 sandwich 92 W@70 μA beam current

- Steady-state thermal analysis

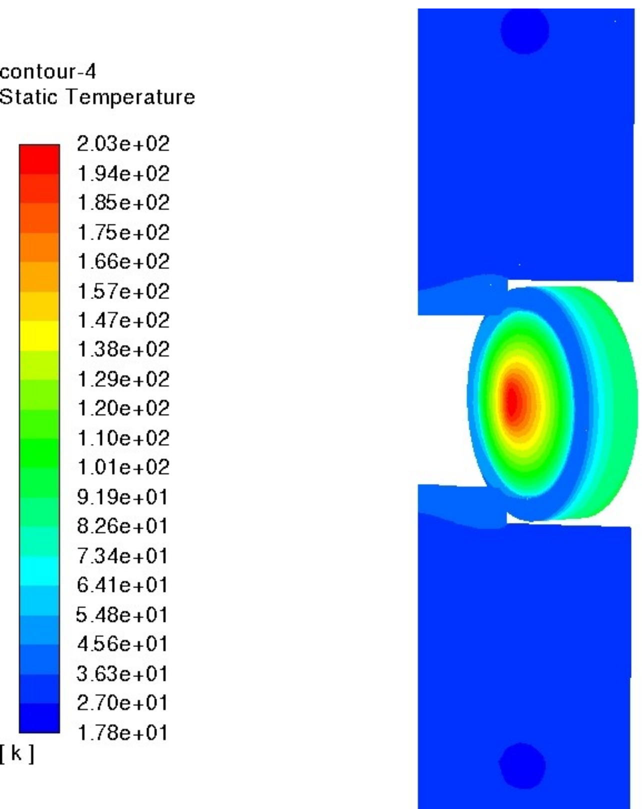
CFDFAC Thermal Analysis



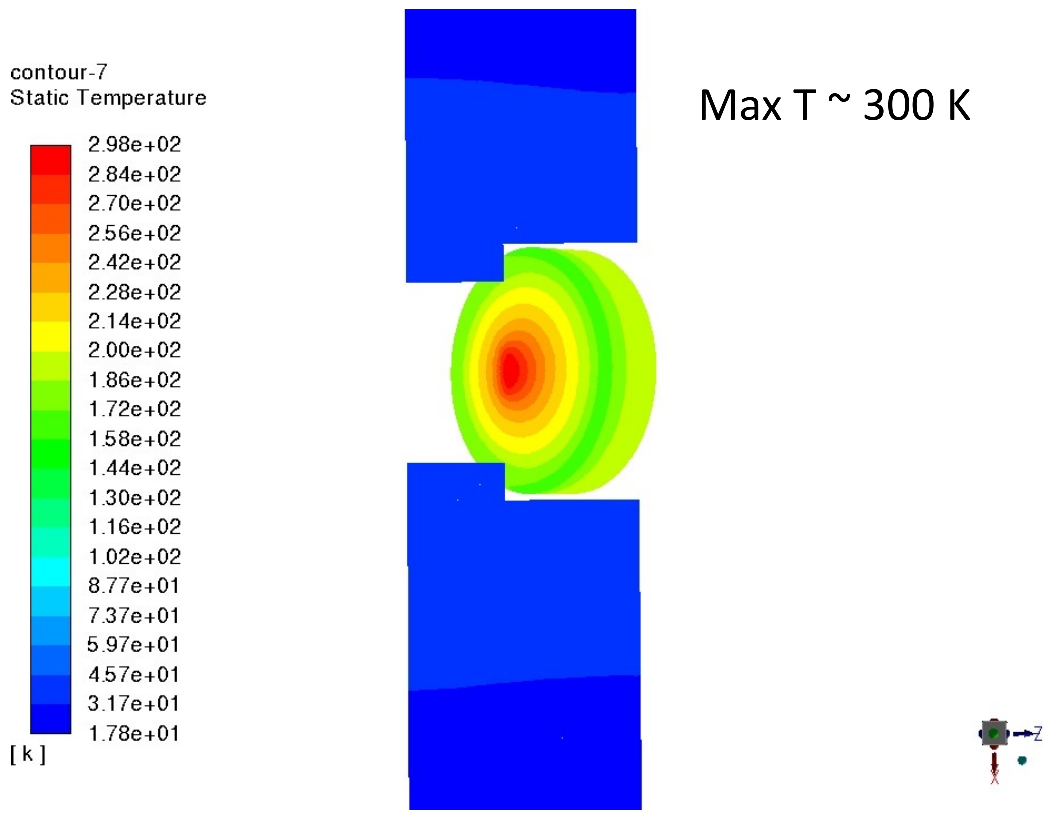
Ca thermal analysis

- Coolant: 15 K, 10 g/s 10 atm He gas from ESR
- Target tilted 45°, beam raster assumed 1 mm by 4 mm, beam current 150 µA, P ~ 368 W
- Temperature profile in Ca and a section through the Cu frame
- Ca melts at 1115 K

Ideal contact Ca-Cu frame, on one side of Ca, max T ~ 203 K



0.2 mm CaO film contact with the Cu frame, on one side of Ca, k_{CaO} = 5 W/m.K



Max T ~ 300 K

Summary

(as presented to the ERR committee, annotated now)

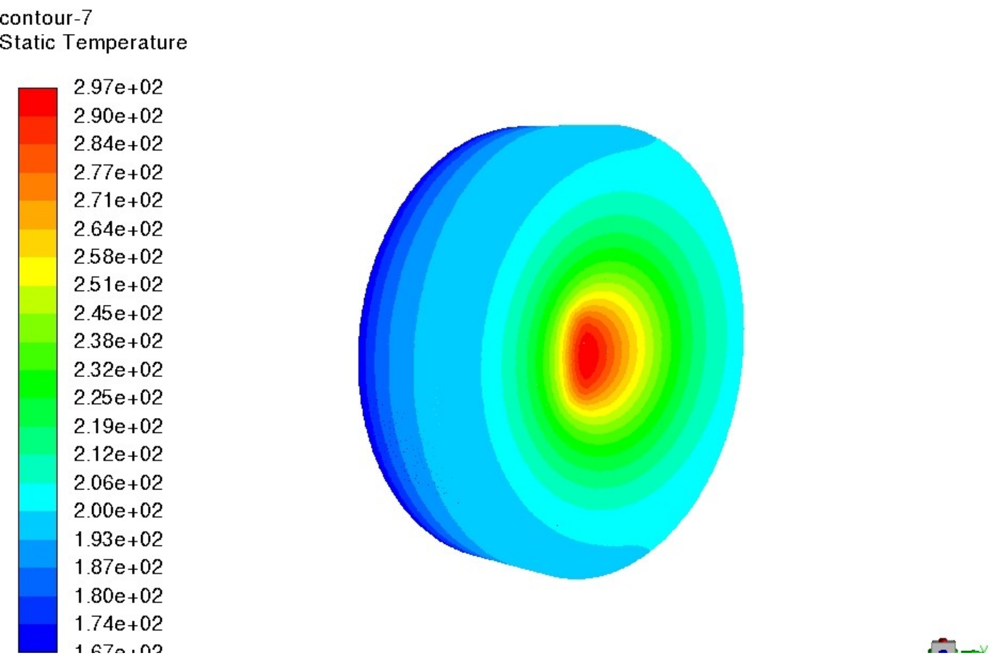
Item 1: The target system is on track to be manufactured by the end of 2017 and be ready for installation in spring 2018 (most of the target could be manufactured 2018, caveat jlab budget)

Item 2: The target chamber will be protected against a beam line vacuum loss by 2 gate valves. The chamber will also be instrumented with an inert gas purge system (still the case)

Item 3: There was no observed flow of melted Pb in PREX1 (item 3 and below are the same)

- CFDFAC time-dependent thermal analysis for C-Pb-C system shows that 4 K cooling is not a cause for melting Pb even with 140 μA beam ON starting at t = 0s.
- Increasing the beam raster frequencies difference lowers the max temperature in Pb; also increasing the intrinsic beam spot size has the same effect
- max_T_Pb (we plan to use 15 K He coolant, 250 μm diamond foils):
  - 2 K lower with 4 K vs. 15 K He coolant
  - 100 K lower with 15 K He vs. 77 K LN2 coolant
  - 5 K lower with 5x5 mm^2 vs. 4x4 mm^2 beam raster (with good diamond)
  - 10 K lower for 250 μm diamond vs. 150 μm diamond (with good diamond)
  - 200 K lower for diamond vs. graphite
  - 20 K lower for beam raster frequencies difference Δf = 480 Hz vs 120 Hz
- max_T_Ca is estimated to be 203 K with 15 K He coolant, 1x4 mm^2 150 μA beam, 45° tilted target with ideal thermal contact Ca-Cu and 300 K if the thermal contact is through a 200 μm layer of a thermal insulator with conductivity 5 W/m.K

Back-up slides


contour-7
Static Temperature
2.97e+02
2.90e+02
2.84e+02
2.77e+02
2.71e+02
2.64e+02
2.58e+02
2.51e+02
2.45e+02
2.38e+02
2.32e+02
2.25e+02
2.19e+02
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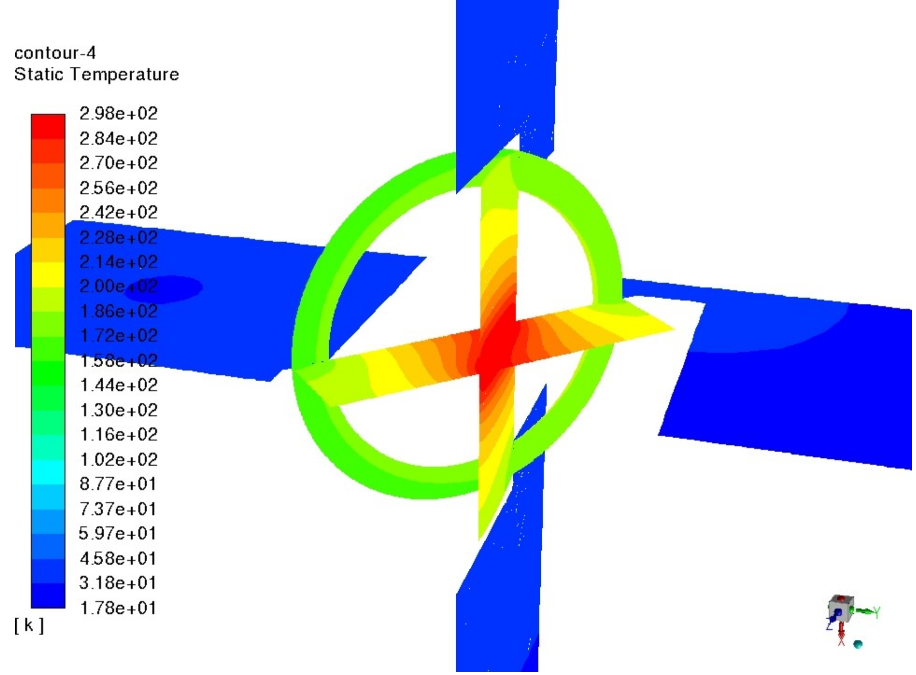
1.80e+02
1.74e+02


contour-4
Static Temperature
2.98e+02
2.84e+02
2.70e+02
2.56e+02
2.42e+02
2.28e+02
2.14e+02
2.00e+02
1.86e+02
1.72e+02
1.58e+02
1.44e+02
1.30e+02
1.16e+02
1.02e+02
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5.97e+01
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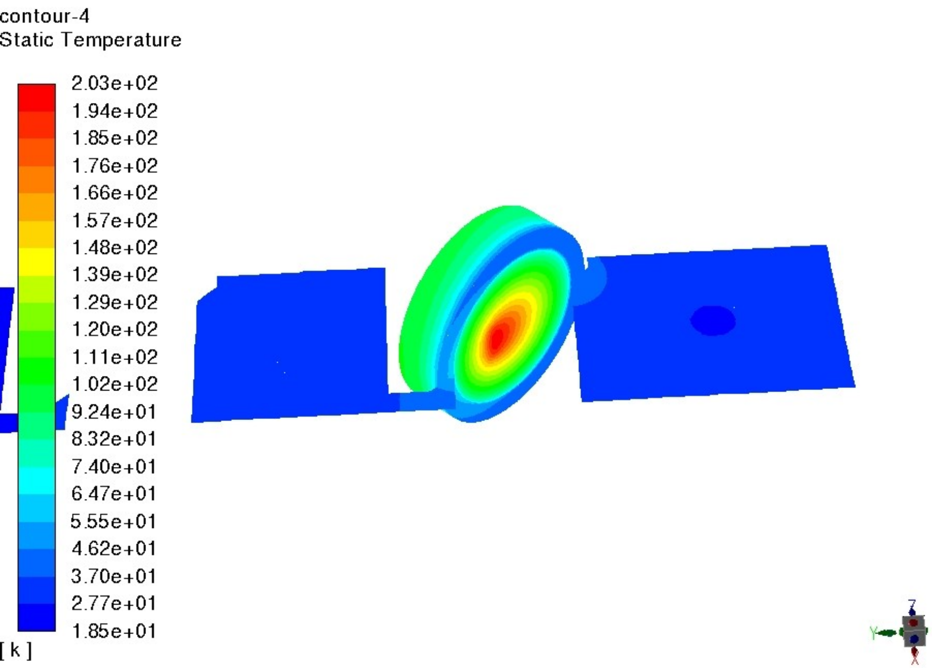
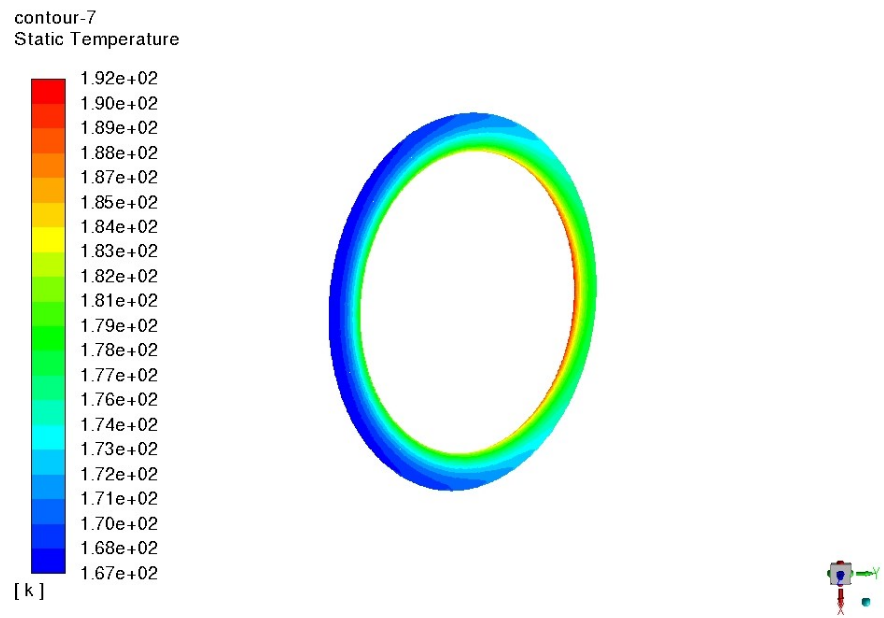
3.18e+01
1.78e+01
[k]

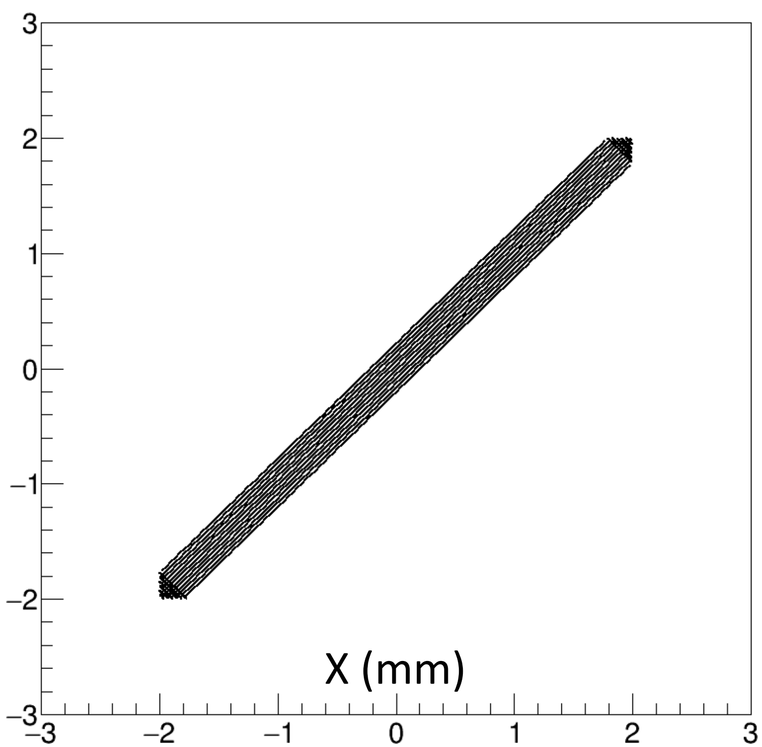

contour-4
Static Temperature
2.03e+02
1.94e+02
1.85e+02
1.76e+02
1.66e+02
1.57e+02
1.48e+02
1.39e+02
1.29e+02
1.20e+02
1.11e+02
1.02e+02
9.24e+01
8.32e+01
7.40e+01
6.47e+01
5.55e+01
4.62e+01
3.70e+01
2.77e+01
1.85e+01
[k]


contour-7
Static Temperature
1.92e+02
1.90e+02
1.89e+02
1.88e+02
1.87e+02
1.85e+02
1.84e+02
1.83e+02
1.82e+02
1.81e+02
1.79e+02
1.78e+02
1.77e+02
1.76e+02
1.74e+02
1.73e+02
1.72e+02
1.71e+02
1.70e+02
1.68e+02
1.67e+02
[k]

The electron beam is moved on the target by a magnetic rastering system, if z is the beam line axis, then the raster deflects the beam along x and y-axes with triangular wave-functions of frequency fx and fy (~25 kHz)

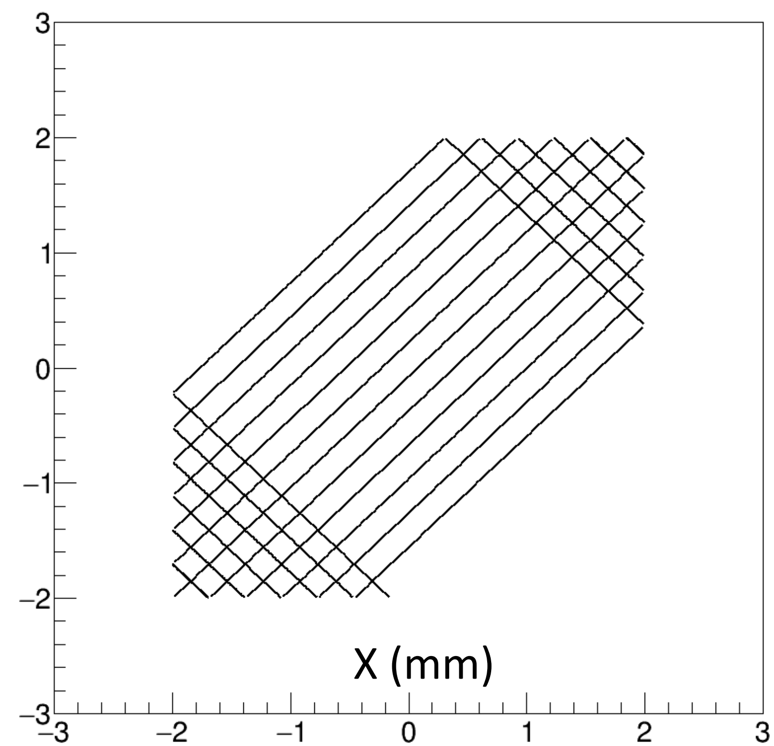
Target area covered by the beam rastering system in the same amount of time for two cases of frequency difference between x and y axis wave forms for a square raster of amplitude 4 mm

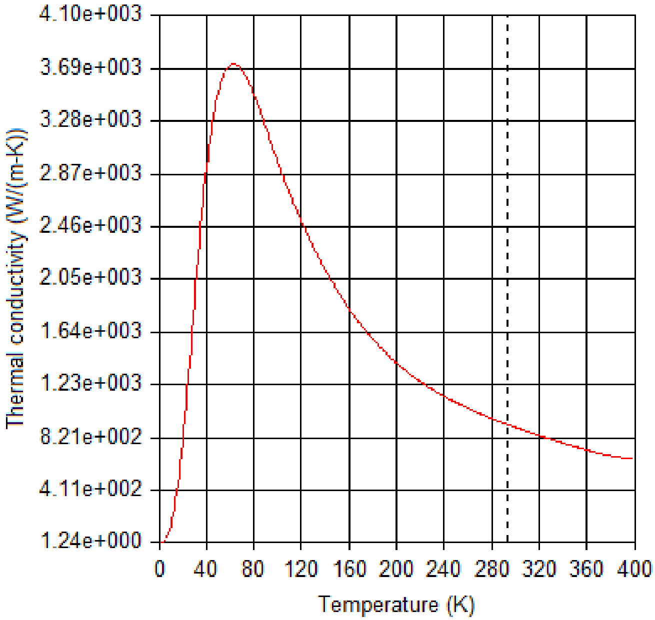
fx – fy = 120 Hz



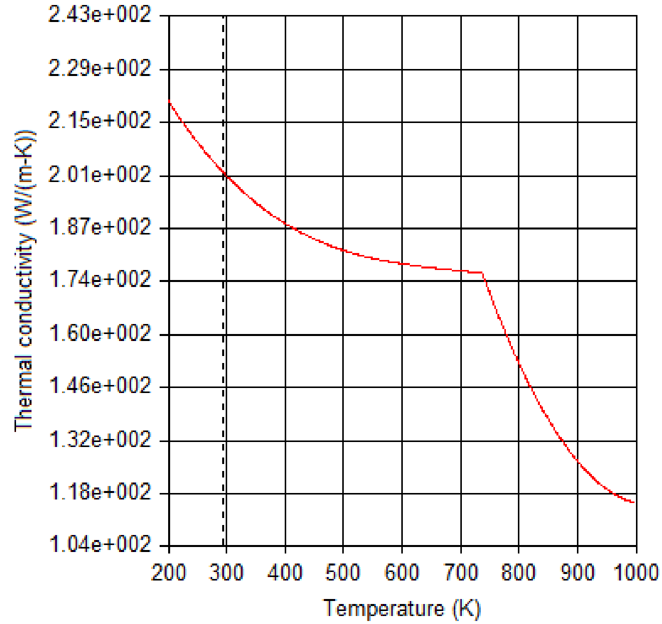
Y (mm)

fx – fy = 960 Hz



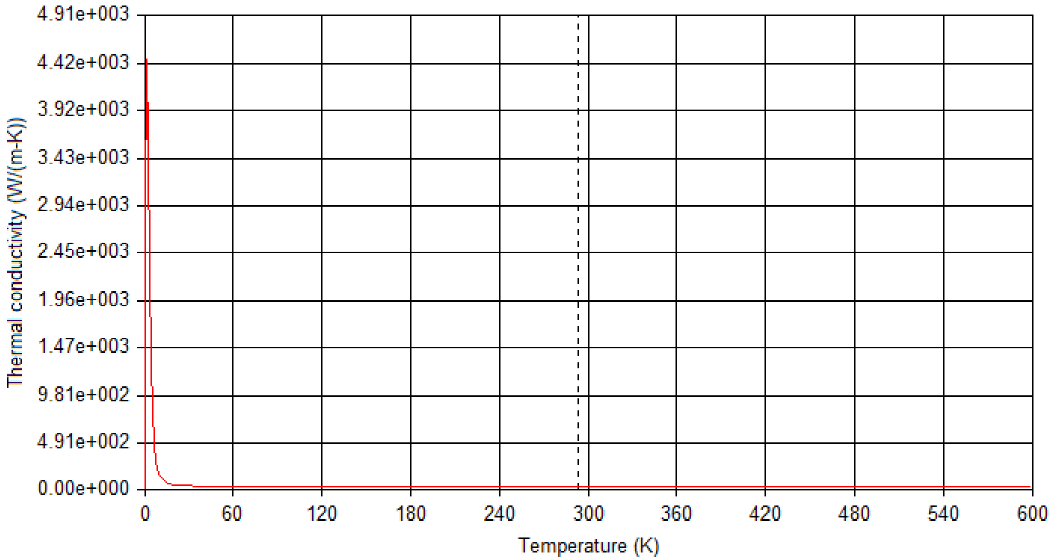


Diamond



Calcium

Lead



CaO