e+ Target Development

Silviu Covrig Dusa

1 Dec 2022

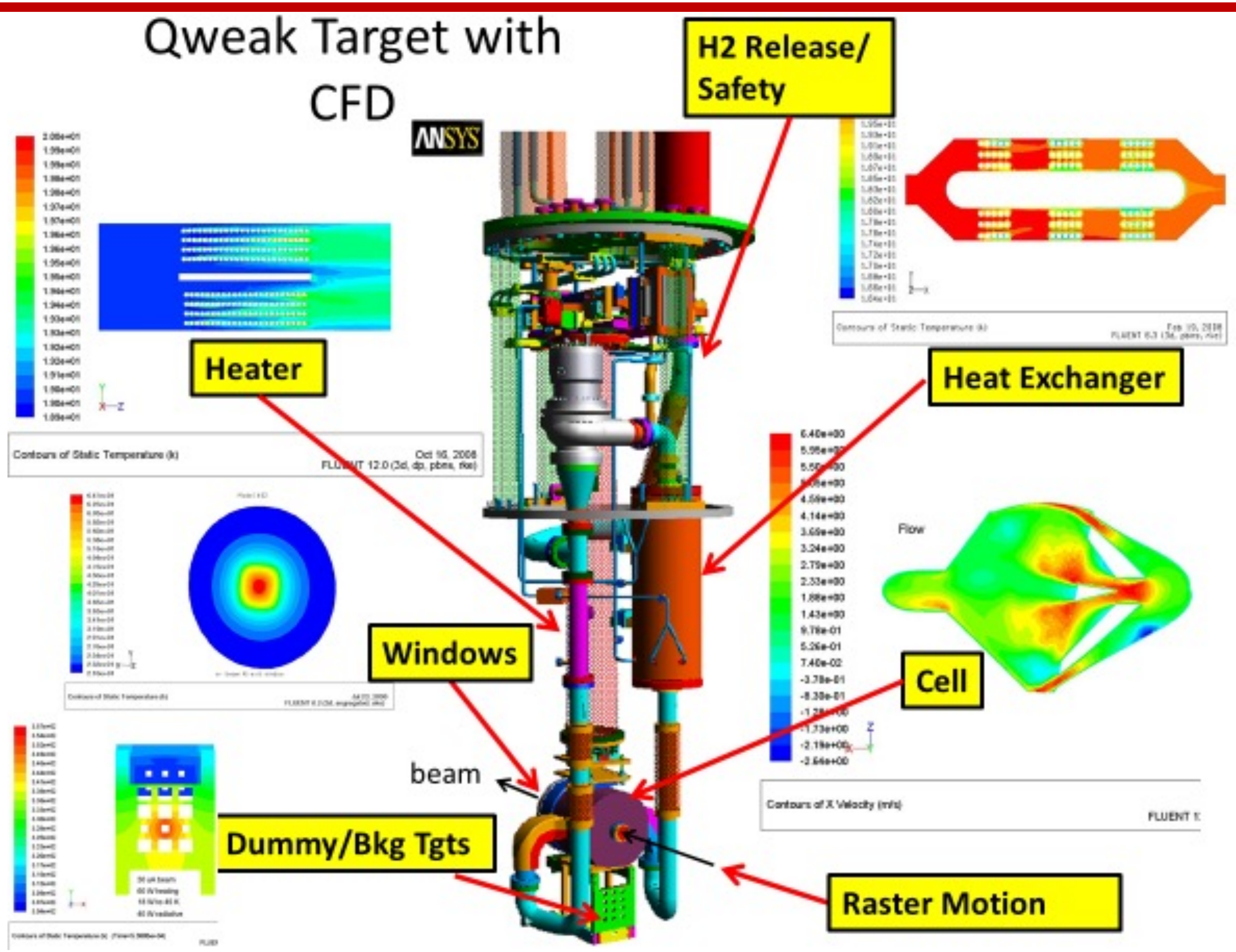
- CFD capabilities @JLAB
- Prototyping a e+ target @JLAB
- CFD for the e+ target

CFD @JLAB

- CFD started being used at Jlab around 2006, first used for designing the 2.5 kW liquid hydrogen (LH2) target for the Qweak experiment (the highest power LH2 target in the world at the time), Qweak was operated between 2010-2012.
- Based on the success of the Qweak target meeting all its design performance requirements, CFD-driven design and/or performance assessment was expanded to all targets in halls A and C @JLAB
- Designed/assessed the thermal performance of solid/liquid/gas targets
- In the process of designing the 4.3 kW LH2 target for the MOLLER experiment
- CFDFAC farm@jlab has access up to 512 CPUs and uses ANSYS-CFD

CFD for the Qweak Target

- CFD driven design was used for all Qweak target loop components except the pump
- H_2 release into Hall C was analyzed with CFD to establish keep-out zones around the target chamber
- Steady-state and time-dependent CFD simulations have been developed
- The CFD design process extended over 3 years starting in 2006
- In the absence of CFD the Qweak would have employed an extended G0 target cell
- The Qweak target cell design started with the extended G0-type cell and morphed into a fully transverse flow to the beam line cell used successfully in 3 run periods (2010-2012)
- The first target designed with CFD at jlab



What has been done with CFDFAC

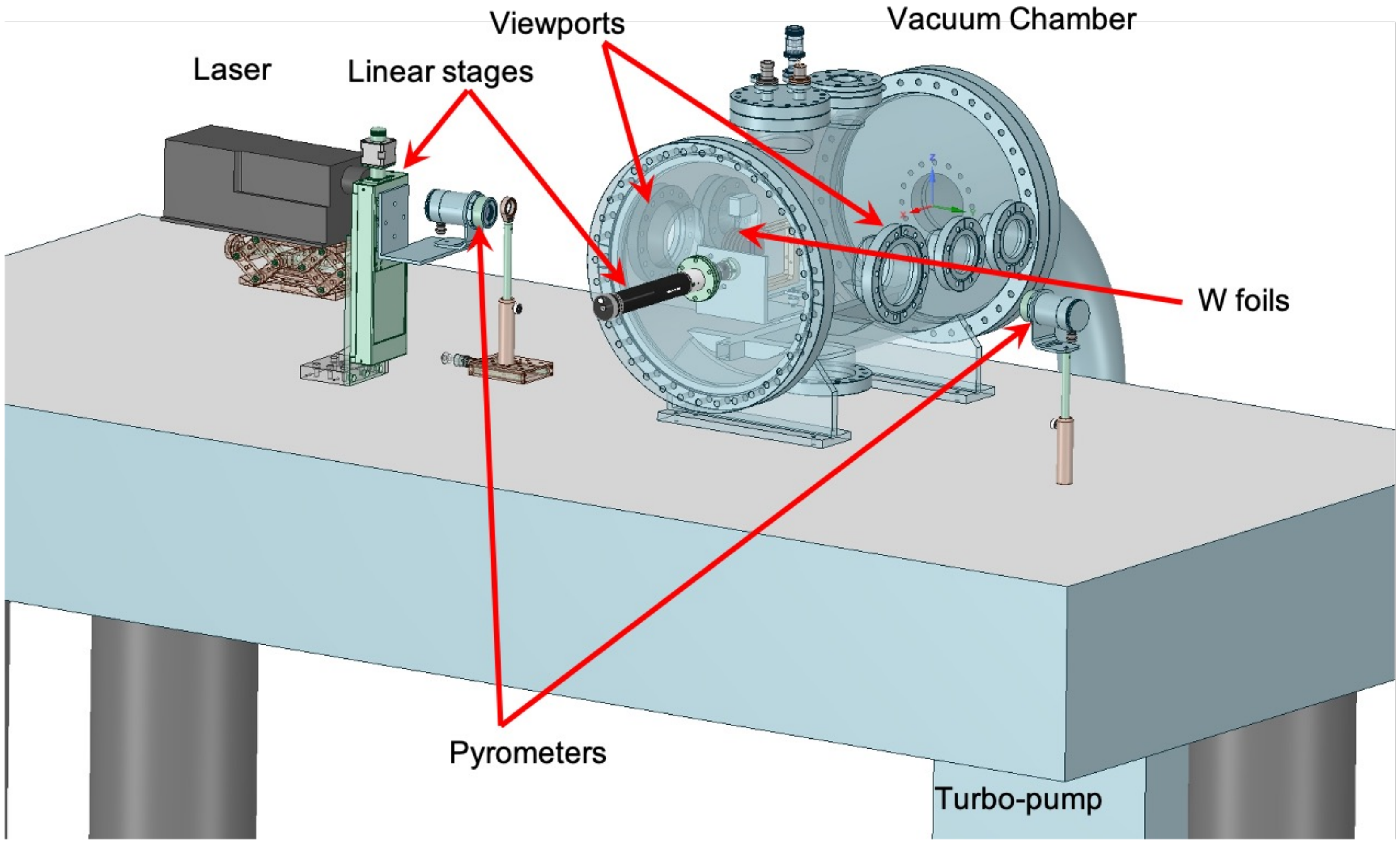
- Assessed most 6 GeV target cell designs used in Halls A and C and found out that performance was limited by geometry and LH2 pump flow
- Designed new standard targets cells for the 12 GeV program (LH2, LD2 or high pressure gas) with lengths extensible to 30 cm and luminosity loss of 1-2% at 100 μA and beam raster area of 4 mm^2
- Designed/assessed a host of targets that have already been used during the 12 GeV program that were not standard (APEX, PREX2, CREX1, tritium/40Ar cell, 3He cell etc.)
- CFDFAC has become a general tool to design/assess experimental equipment at jlab (not just targets, any experimental equipment where thermodynamics plays a role in performance)

Prototyping a e+ target @JLAB

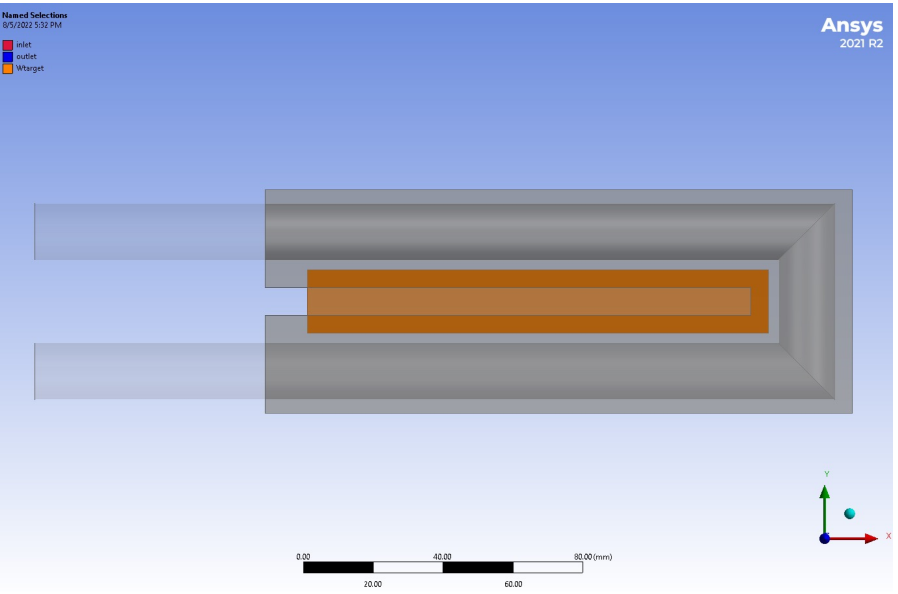
- Road to a positron target in two stages
    1. Prototype a static target, operate and characterize (1-3 years, part of this proposal)
        - Design and engineer a static target
        - Thermally assess 3 target materials (W, W-Re, W-Cu) with a high power laser bench setup
        - Build a static target and install
        - Operate the static target with e-beam, extract e+ beam and characterize
    2. Prototype a high power (>15 kW) target
        - Based on the experience from step 1. develop a prototype high power e+ moving target
        - Commission the prototype e+ target with beam
        - Develop a production e+ target and operate for physics
- We are working on step 1

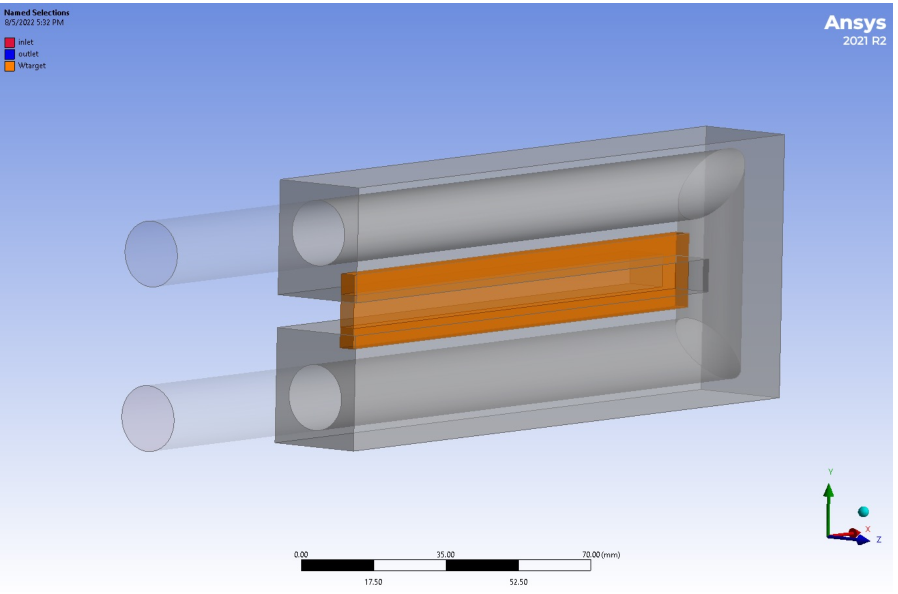
Thermal Assessment Experimental Setup

- This setup was used to perform a thermal assessment of the W foils for the APEX experiment using a high power laser and compare with CFD simulations
- We are in the process of reassembling the setup for target material thermal characterization for a e+ target

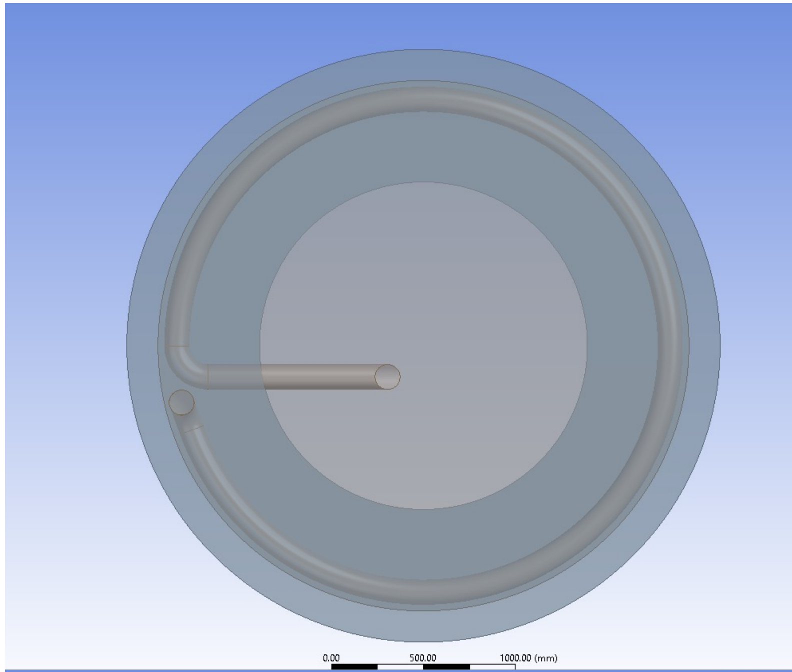


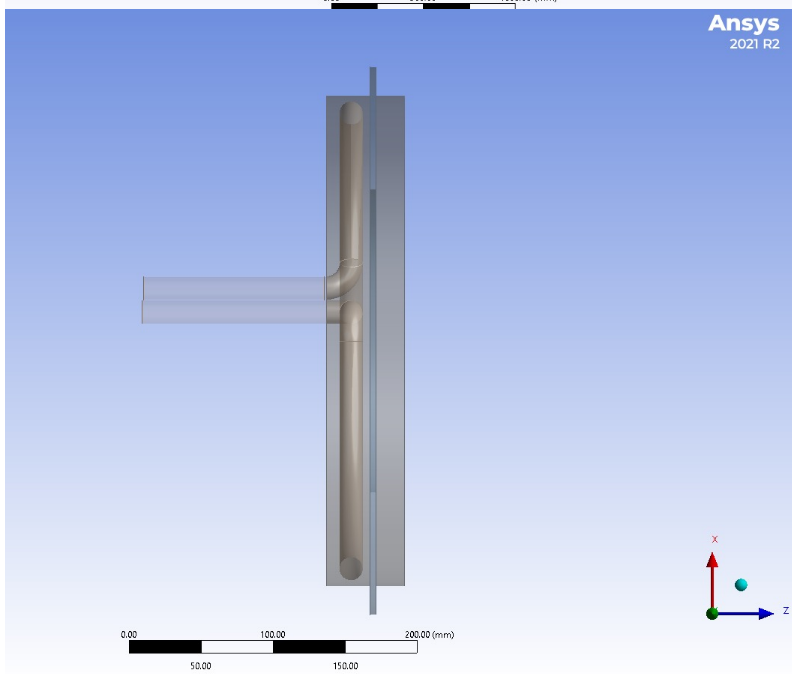
CFD for the e+ target



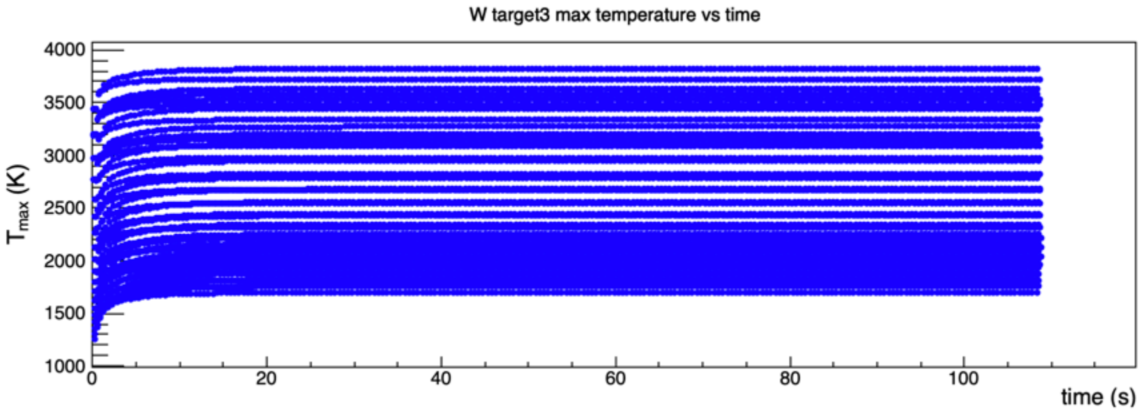


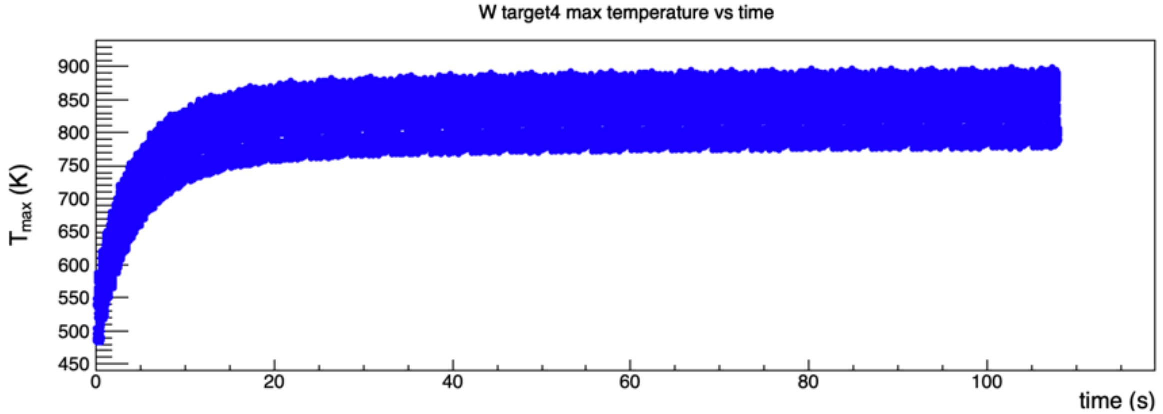
- Two designs considered, so far, a linear moving target (left) and a rotating target (right)
- Both targets are considered to be made out of W, 4 mm thick for beam
- The e-beam deposits 17 kW, the beam area is 4x4 mm^2
- The target frames are made of Cu and cooled with water
- The rotating target is based on a design by A. Ushakov

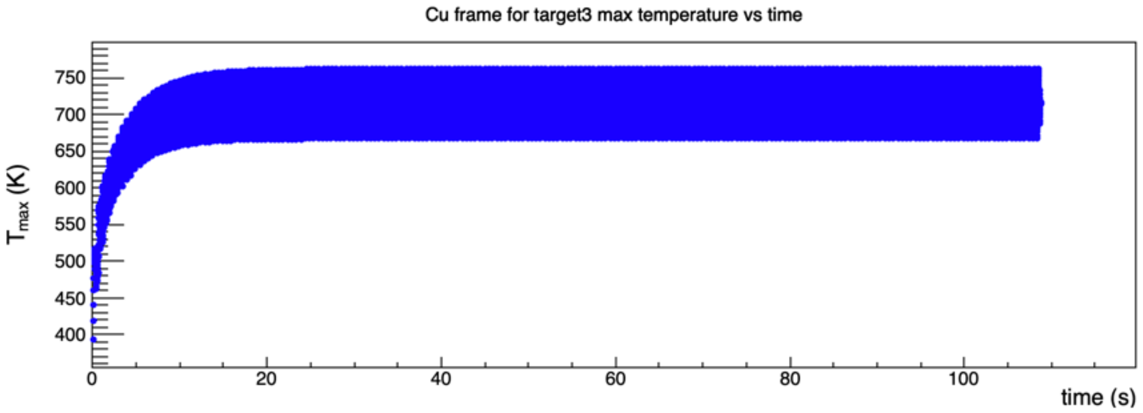


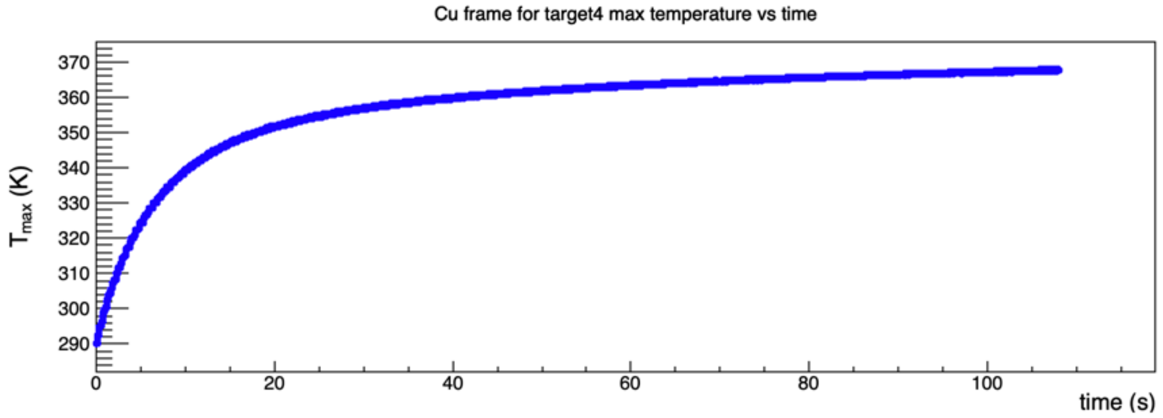


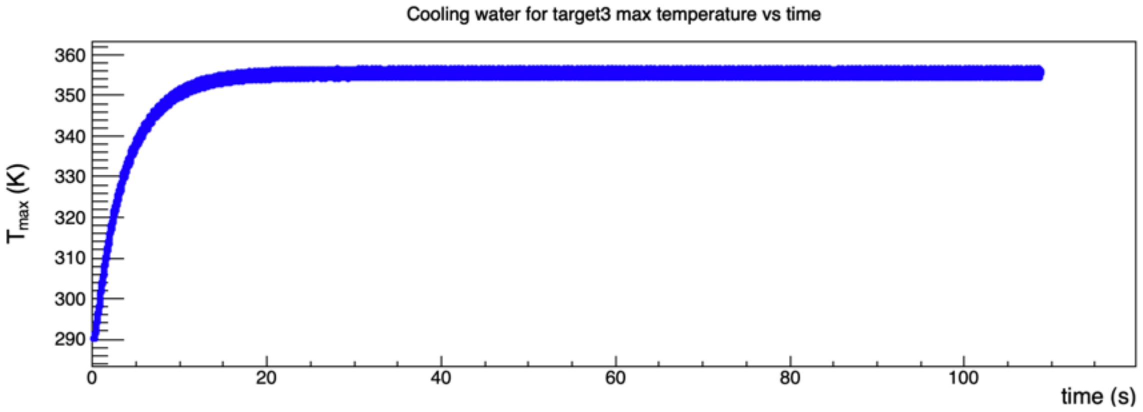
Summary plots: target 3 = linear moving; target 4 = rotating

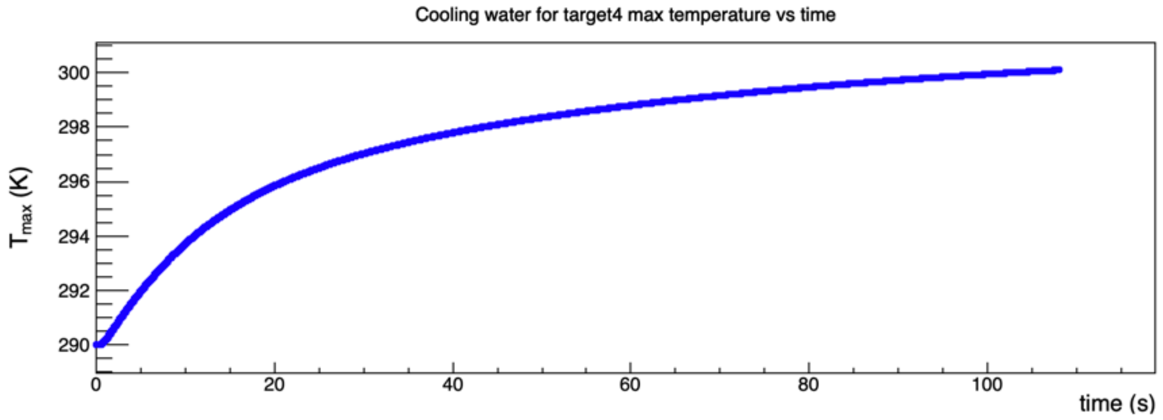








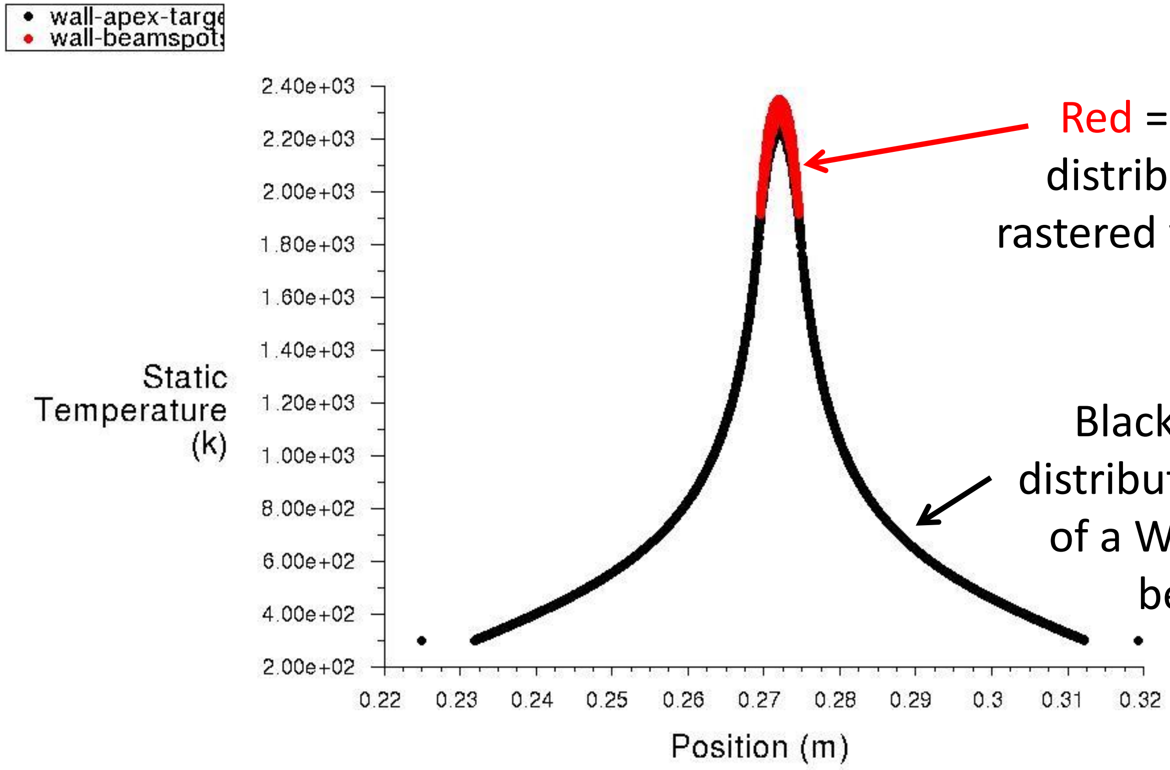




Backup Slides

Temperature distribution in a 15 µm thick, 8 cm long, 2.5 mm wide W foil, ε = 0.15, at 150 µA beam rastered 1.5x5 mm^2

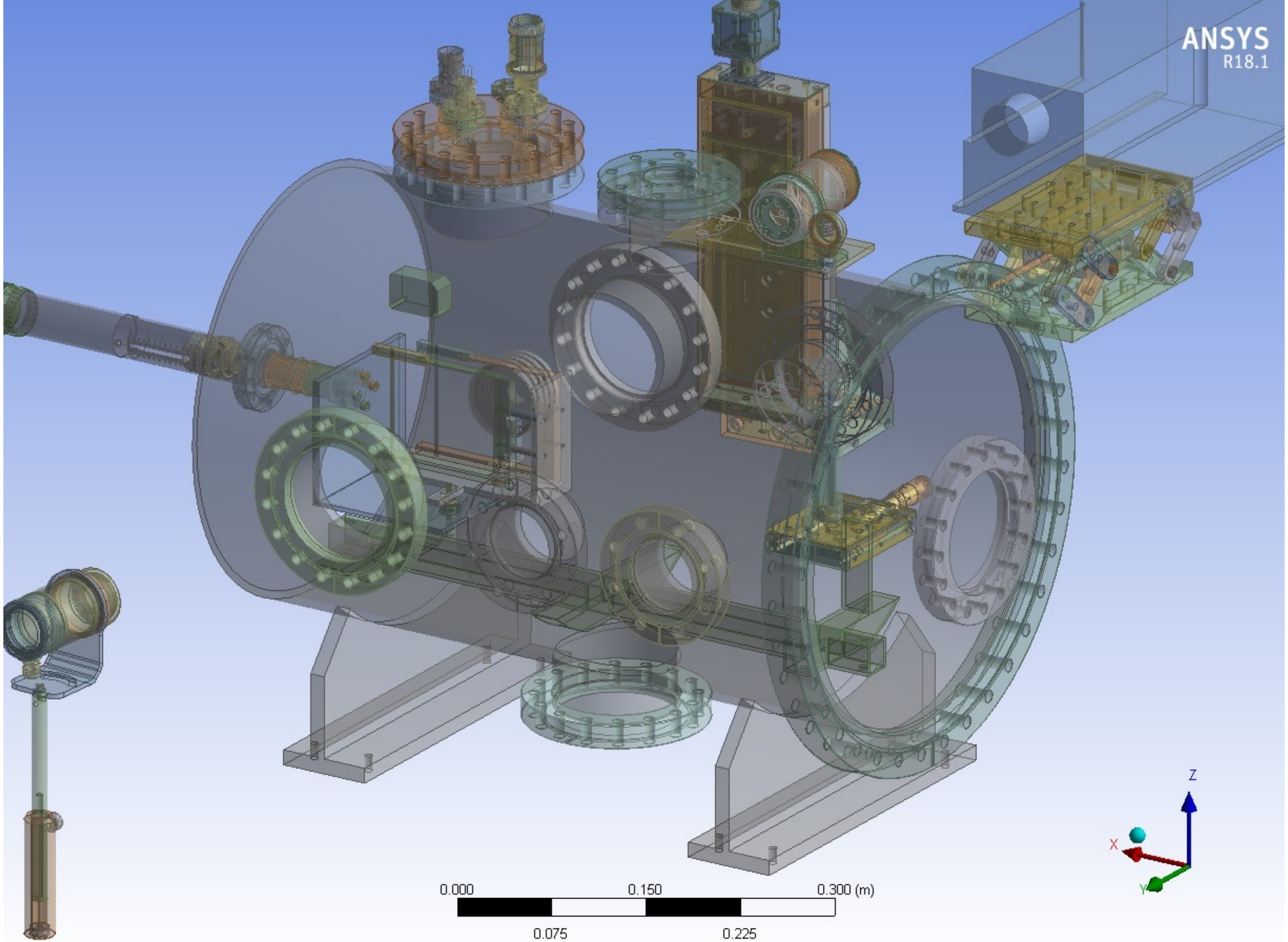
APEX target



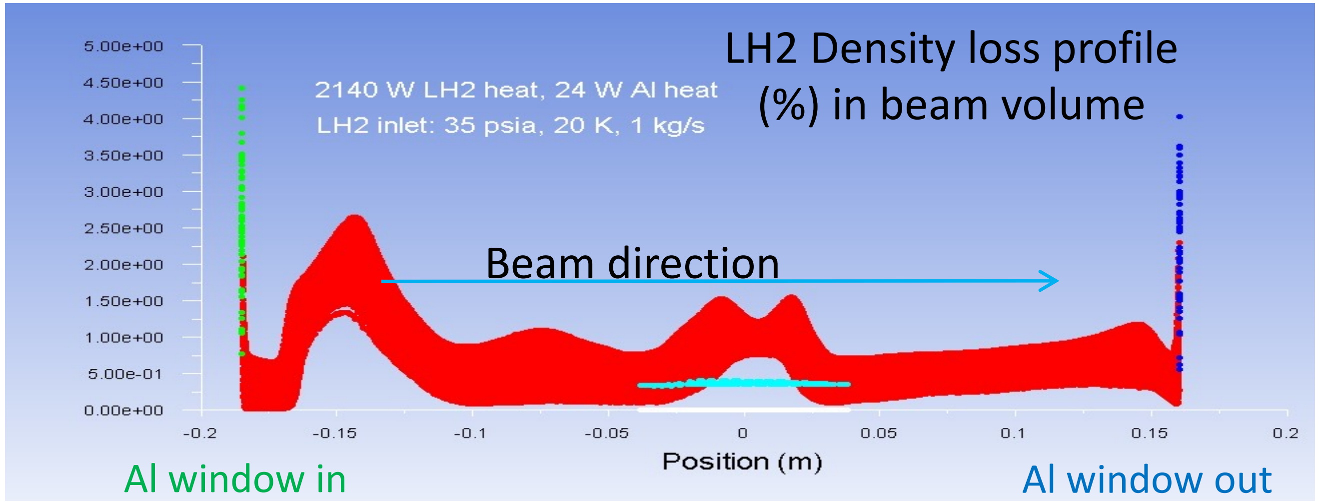
Red = temperature distribution in beam rastered volume in the W foil

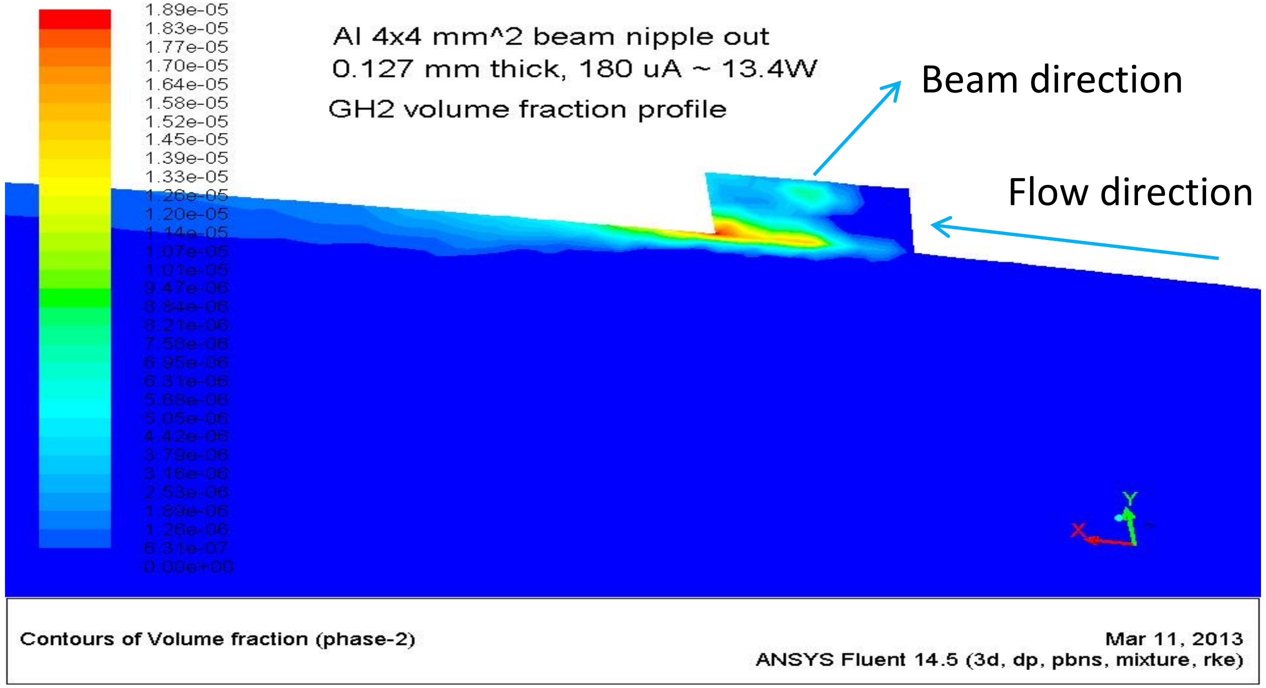
Black = temperature distribution in the volume of a W foil, outside the beam volume

The length, thickness and thermal conductivity of a W foil make the temperature at its ends only a few degrees above the environment's temperature, a W foil radiates ~ 90% of the beam heating deposited in it


ANSYS
R18.1
0.000
0.150
0.300 (m)
0.075
0.225
Z
X
Y

Qweak Target Performance





The Qweak target cell with Fluent at 180 μA beam, rastered 4x4 mm^2, LH2 in at 1 kg/s

CFD predicted average LH2 relative density loss in beam volume

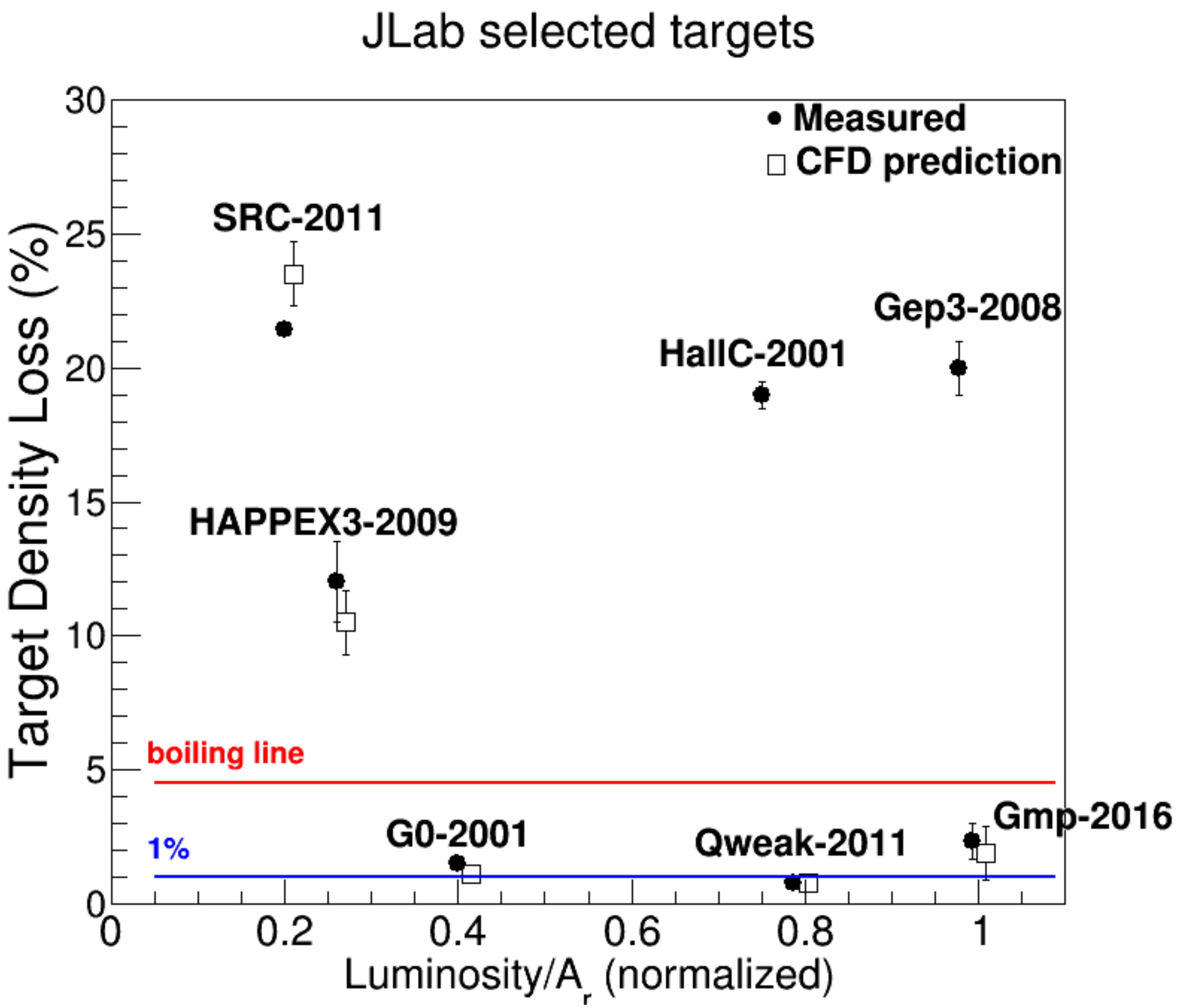
$\Delta\rho/\rho \sim 0.8\%$

(measured 0.8% det. yield loss at 180 μA)

We measured LH2 density fluctuations <50 ppm at 480 Hz

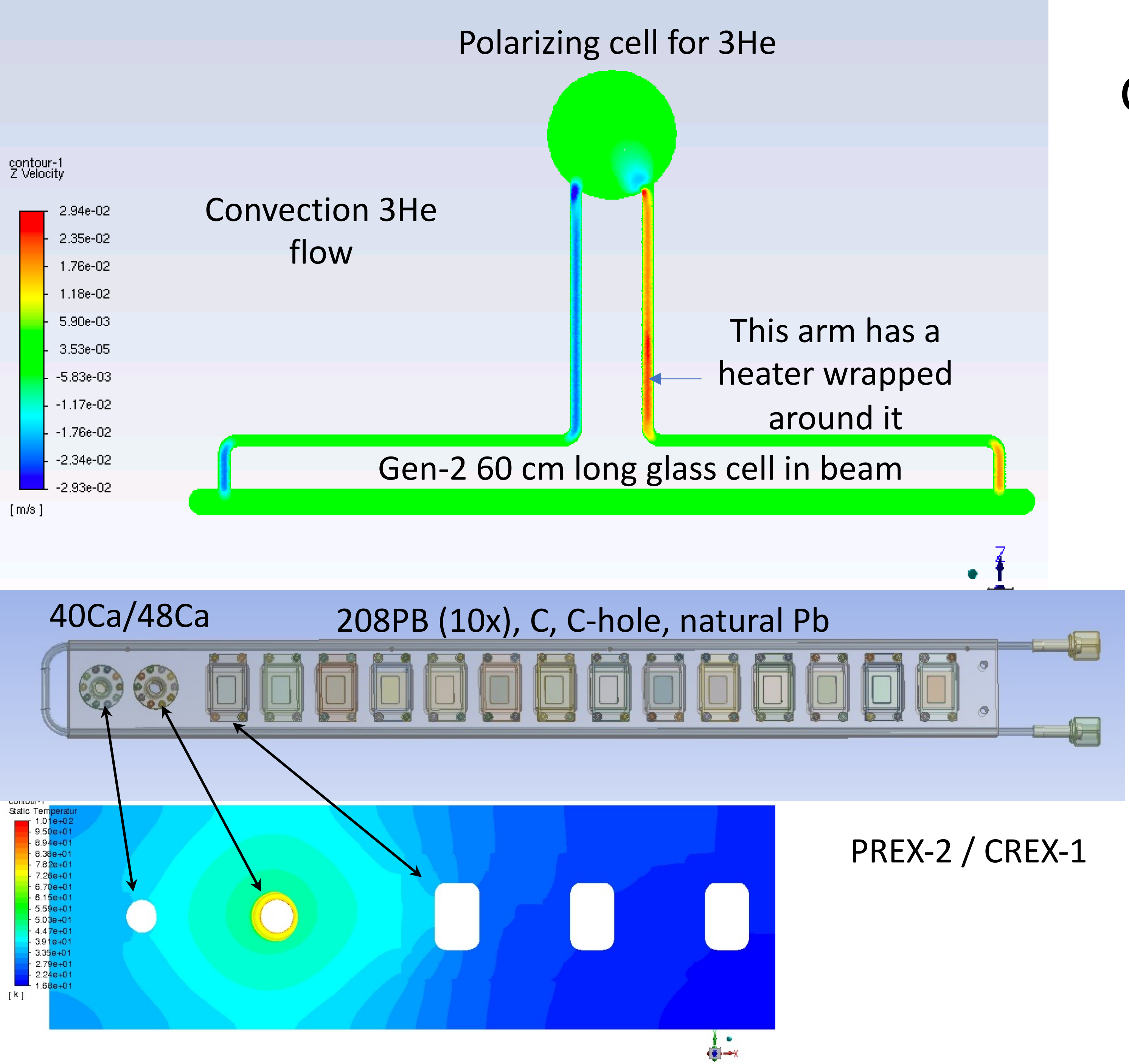
Electron beam heating at the Al windows

LH2 boiling observed with a 2-phase mixture model in Fluent



JLab selected targets
Measured
CFD prediction
SRC-2011
Gep3-2008
HallC-2001
HAPPEX3-2009
boiling line
1%
G0-2001
Qweak-2011
Gmp-2016
Target Density Loss (%)
Luminosity/A_r (normalized)
0
5
10
15
20
25
30
0
0.2
0.4
0.6
0.8
1

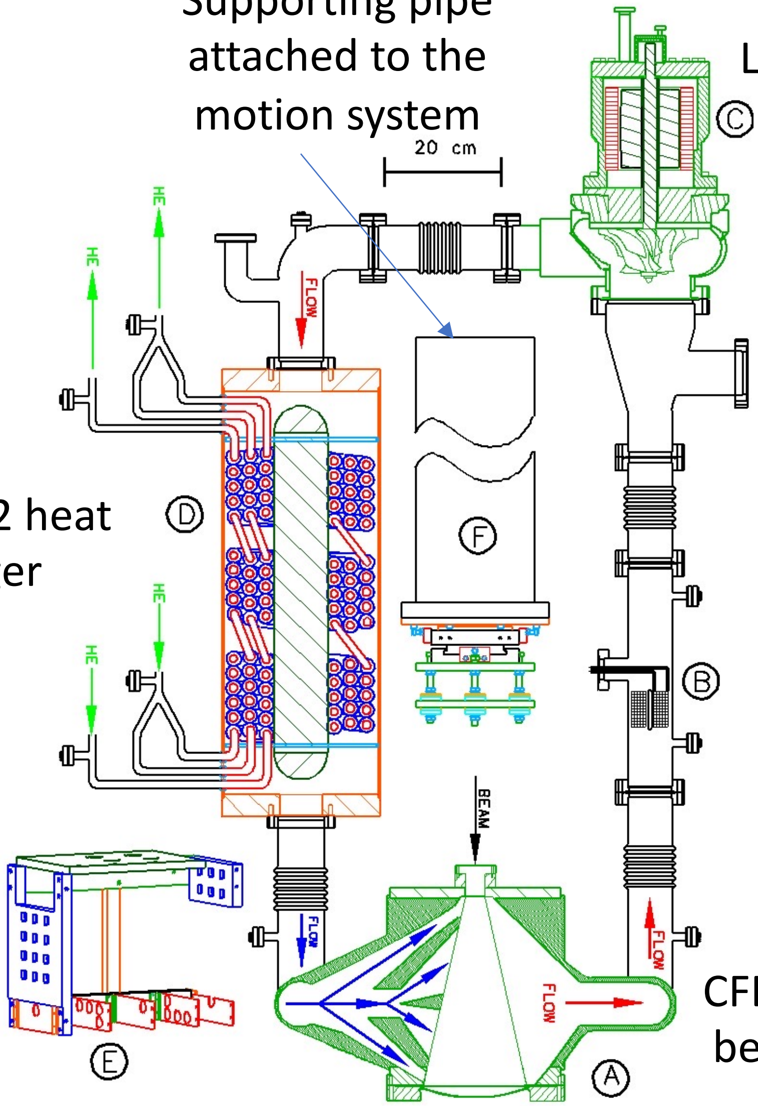
Gen-2, PREX-2, CREX1 targets



PREX-2 / CREX-1

The Qweak Target Loop

55 liters of LH2, the highest power LH2 target in the world at the time



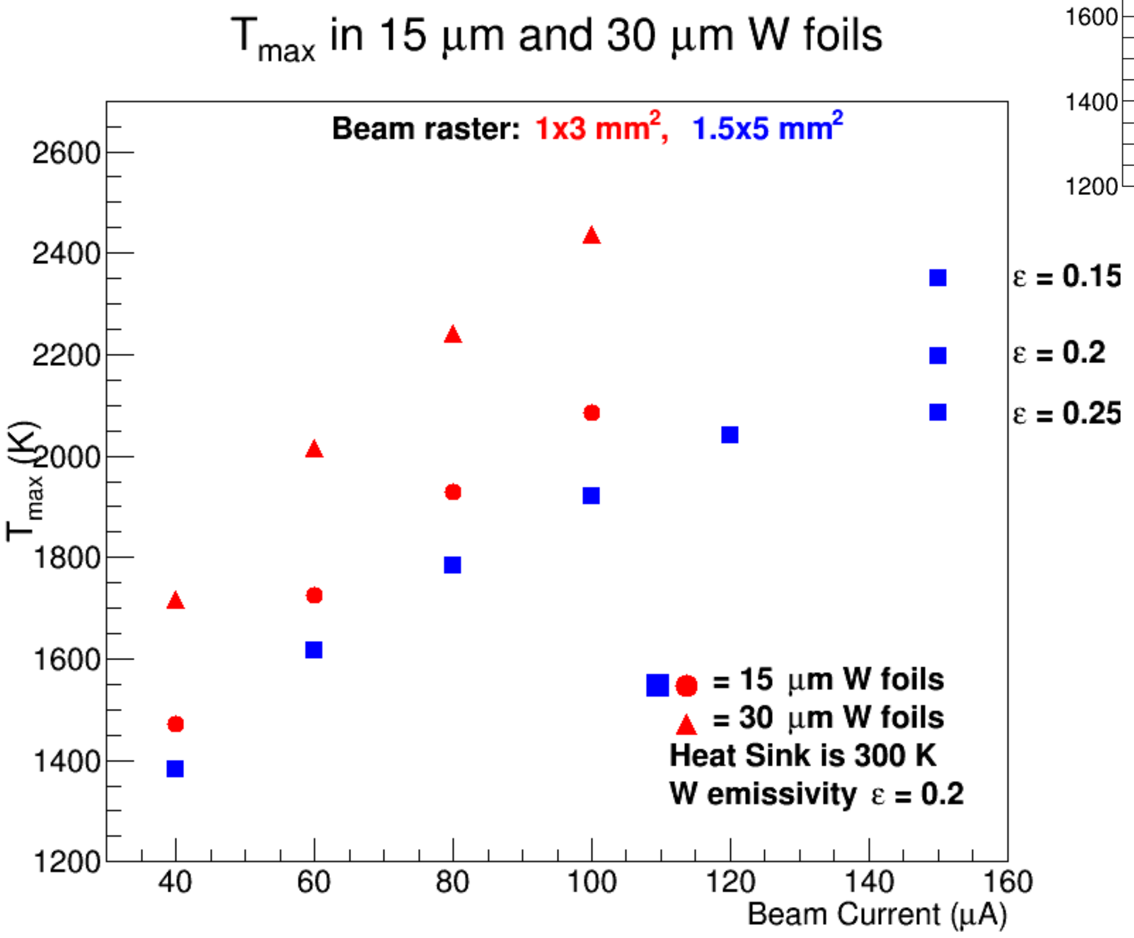
What is CFDFAC

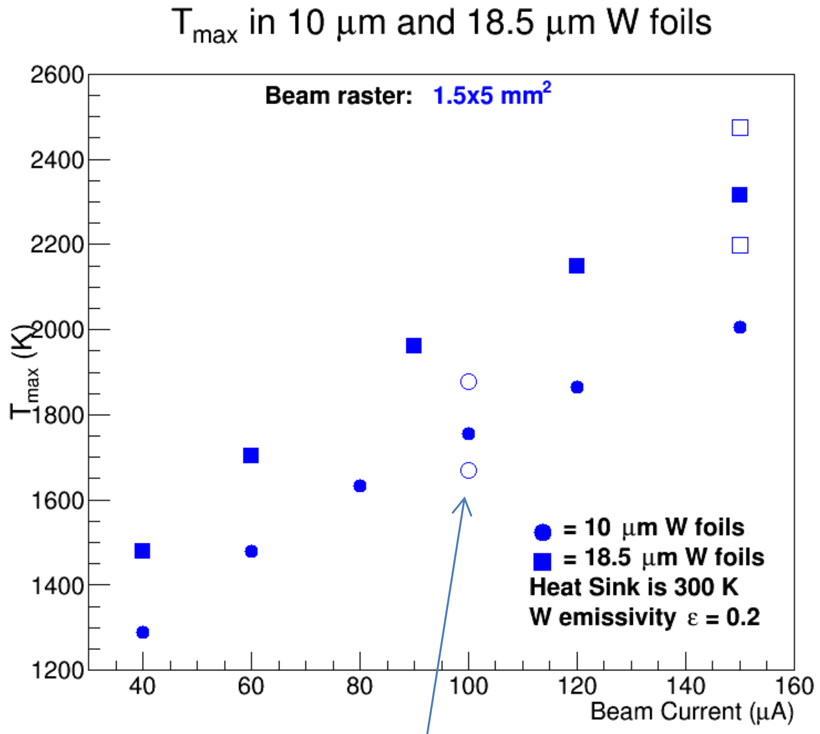
- In 2012 I got a DOE Early Career Award with two original goals:
  - Design a general purpose low noise standard high power (up to 1000 W) liquid hydrogen (LH2) target to be used in Halls A and C at jlab for the 12 GeV era
  - Design a very low noise 5 kW LH2 target cell for the MOLLER experiment which will achieve the requested performance (luminosity loss of less than 1% at 5 kW and with a LH2 density fluctuations of less than 30 ppm at 960 Hz)
- In 2016-2017 I established the CFDFAC = Computational Fluid Dynamics FACility with funding from the DOE award to continue the CFD work beyond the award's lifetime
- CFDFAC is a High Performance Computing (HPC) farm at jlab with 256 CPUs running ANSYS-CFD (in 2012 Fluent Inc was aquired by ANSYS and *fluent* became ANSYS-Fluent, now part of ANSYS-CFD along with CFX, ANSYS's original CFD software; Fluent and CFX have not merged, they are separate CFD softwares)
- CFDFAC has been up and running at jlab for the last 5 years

CFDFAC: selection of targets

Target	material	L mm	P / I W / μA	beam spot mm	Work done	E GeV
PREX-2	C-208Pb-C	0.55	100 / 70-85	4x5	Design/assessment	1.1
CREX-1	40Ca/48Ca	5	340 / 150	2x2	Design/assessment	2.2
Marathon	3H/H	250	4 / 22	2x2	assessment	several
APEX	W	0.1	80/ 100	1x5	Design/assessment	several
A1n/d2n	3He	400	5 / 30	4.5	Assessment/some design	several
Standard	LH2/LD2	<300	500 / 100	2x2	Design/assessment	several
MØLLER	**LH2**	**1250**	**4300 / 70**	**5x5**	**Design/assessment**	**11**
Gen-2	**3He**	**600**	**8 / 60**	**6**	**Assessment/some design**	**several**
P2	**LH2**	**600**	**4000 / 150**	**5x5**	**Assessment/some design**	**0.15**

APEX Target Thermal Studies Summary





Open marks are for tungsten emissivity of 0.15 and 0.25 respectively