Summary of the Absorber Temperature Calculations

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What Has Been Done?

- Several conditions have been simulated with FLUKA for each model.
  - Quite a bit of effort from Vitaly and Pavel.
- The power deposition data have been analyzed with Mathematica
  - I can use both rectangular mesh or cylindrical mesh.
  - Cylindrical mesh is good when the axis is near the hot spot
    - Relatively small mesh and faster analysis (~2-3hrs per condition) .
    - Problems with boundary conditions when they involve the temperature gradient.
      - Workarounds and hacks are needed.
    - Most likely has larger uncertainties than rectangular mesh with a fine element size for the solver.
  - Rectangular mesh needs to have much finer element sizes near the hotspot.
    - Larger mesh and longer run times (16-24hrs per condition)
    - Simple to setup the model and the mesh.
- The sets were analyzed with cylindrical mesh in the solver.
  - For Vitaly's data, I converted the cylindrical grid coordinates to Cartesian .
- Some of the outstanding settings were analyzed with rectangular mesh.
- The thermal analysis in complete
  - Tim needs to check the static structural analysis in ANSYS to check for safety factors and margins.

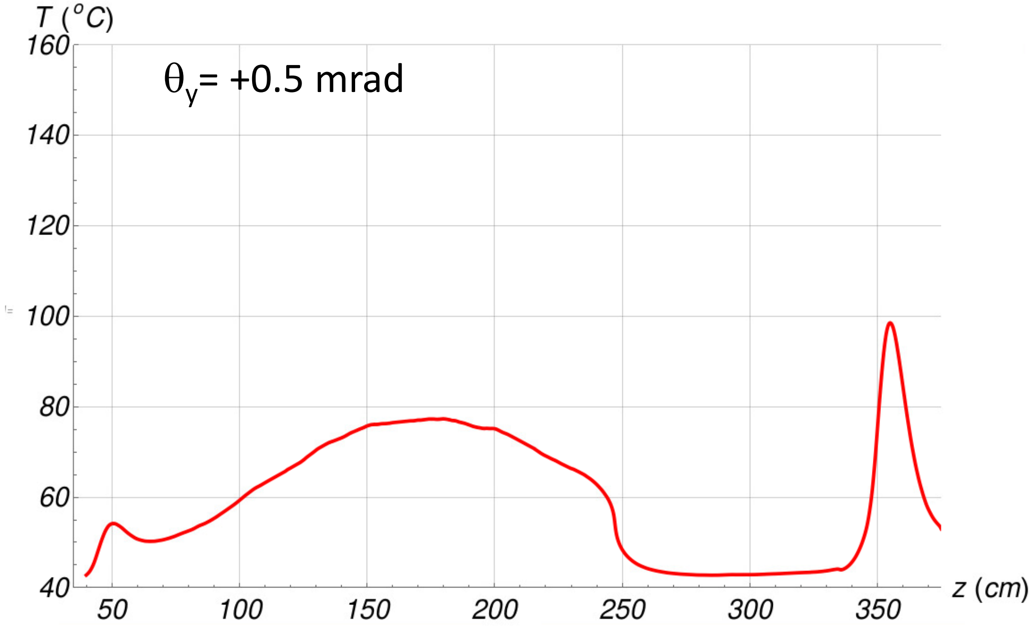
"BC-65-m23" Test Summary (Vitaly)

Test Configuration Name	R_{max} (cm)	ϕ_{max} (deg)	Z_{max} (cm)	T_{max} (°C)	T_{cold} (°C)	Maximum power (KW/cm³)
All Nominal ($\sigma^{(x,y)}_{beam}$ = 1 mm, 4 holes)	0.32	-90	135	90	50	2.9 (Total 53 KW)
$\sigma^{(x,y)}_{beam}$ = 0.33 mm	0.32	-90	140	135	55	8.0 (Total 53 KW)
$\sigma^{(x,y)}_{beam}$ = 1.5mm	0.32	-90	50	120	55	1.8 (Total 53 KW)
90% B-field	0.32	-90	150	88	50	2.5 (Total 53 KW)
110% B-field	0.32	-90	120	102	55	7.0 (Total 53 KW)
-1mm shift in Y	0.33	-90	50	145	55	4.2 (Total 54 KW)
+1mm shift in Y	0.32	-90	165	90	50	2.7 (Total 53 KW)
-0.5mrad angle in Y	0.32	-90	100	110	50	3.7 (Total 54 KW)
+0.5mrad angle in Y	0.65	-90	355	100*	50	2.2 (Total 52 KW)
+1mm shift in X	0.32	-75	57	105	50	2.4 (Total 51KW)
+0.5mrad angle in X	0.32	245	120	90	50	3.0 (Total 54 KW)
20% radiator thickness	0.32	-90	115	90	50	2.3 (Total 49KW)

Check with a Fine Rectangular Grid for ΔZ = 1m absorber section

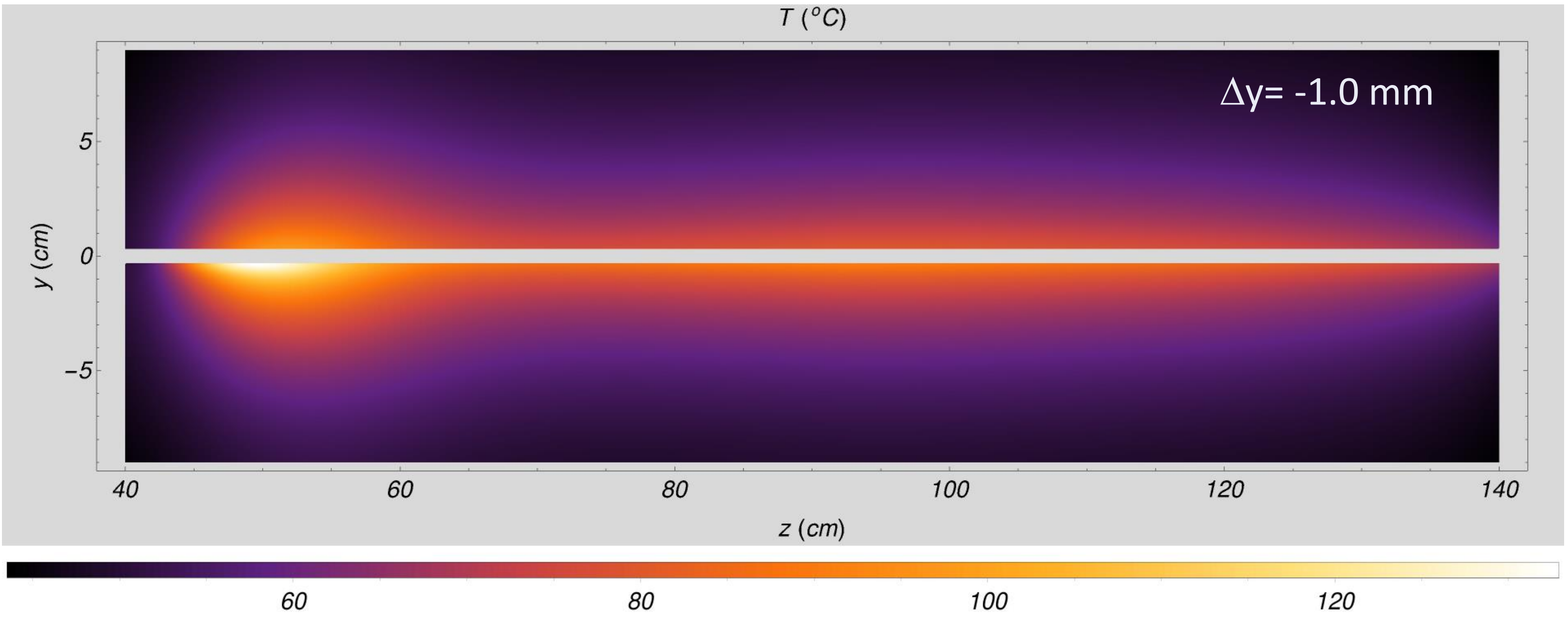
Nominal , 1m long in Z	0.32	-90	135	86	50	2.9
$\sigma^{(x,y)}_{beam}$ = 0.33 mm , 1m long in Z	0.32	-90	140	120	55	8.0
-1mm shift in Y, 1m long in Z	0.37	-90	50	135	55	4.2

Potential Problems and Mitigations (Vitaly)



- At larger vertical angles (500 μrad), the beam can penetrate deep into CPS passed the second magnet.
  - Temperatures will be OK
  - There might be radiation issues.
  - Large angles should be prevented by an interlock on the photon beam position.

- At lower beam position (-1mm), at horizontal offsets (1mm), or wider beam (σ=1.5mm), the hot spot is just before the first magnet
  - There should not be high temperature issues.
  - Radiation dose rate to the magnet might be elevated.
  - The beam positions should be monitored and interlocked.
  - The beam width needs to be measure on a regular basis with wire scans.



KLCPS69 Test Summary (Pavel)

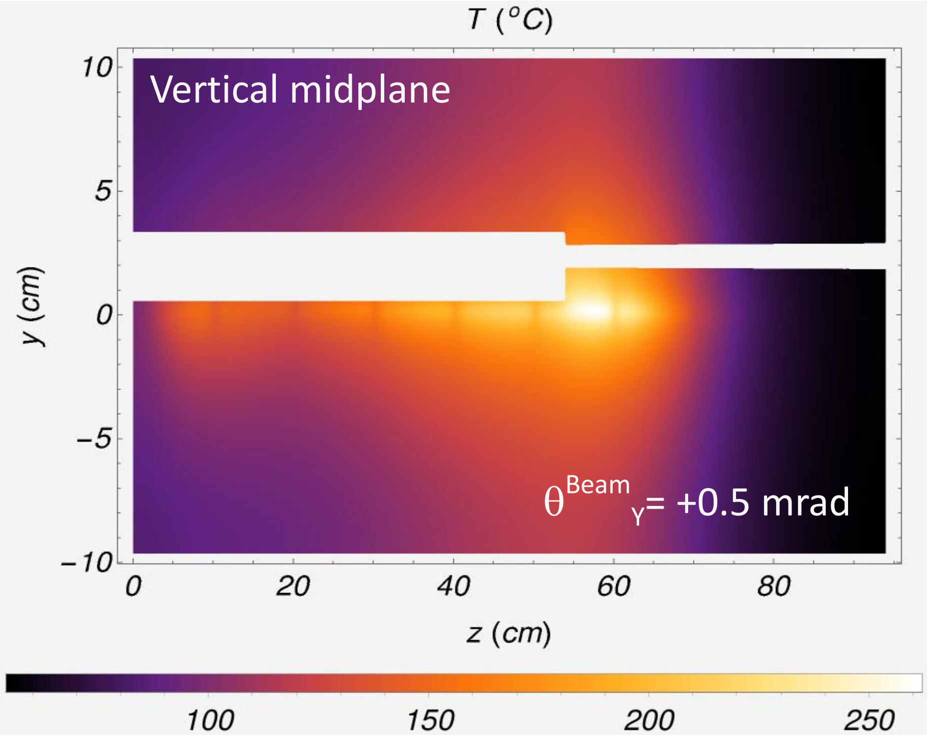
Test Configuration Name	Hot Spot Location Section	R_{max} (cm)	ϕ_{max} (deg)	Z_{max} (cm)	T_{max} (^oC)	T_{cold} (^oC)	Maximum power (KW/cm^3)
All Nominal ($\sigma^{(x,y)}_{beam}$ = 1 mm, 4 holes)	Keyhole	0.04	+90	37	200	55	7
$\sigma^{(x,y)}_{beam}$ = 0.33 mm	Keyhole	0.1	+90	43	250	65	14
$\sigma^{(x,y)}_{beam}$ = 1.5 mm	Keyhole	0.2	+90	8.5	205	55	5
97% B-field	Circular	0.15	+90	58.5	205	60	8
103% B-field	Keyhole	0.1	+90	33	200	55	7
-1mm shift in Y	Keyhole	0.2	+90	8	220	60	7
+1mm shift in Y	Circular	0.1	+90	57	225	60	6.5
-0.5mrad angle in Y	Keyhole	0.2	+90	8.5	220	60	6.5
+0.5mrad angle in Y	Circular	0.15	+90	58	235	60	7
+1mm shift in X	Keyhole	0.5	+70	7.5	245	60	6
+0.5mrad angle in X	Keyhole	0.45	+70	8	250	60	6

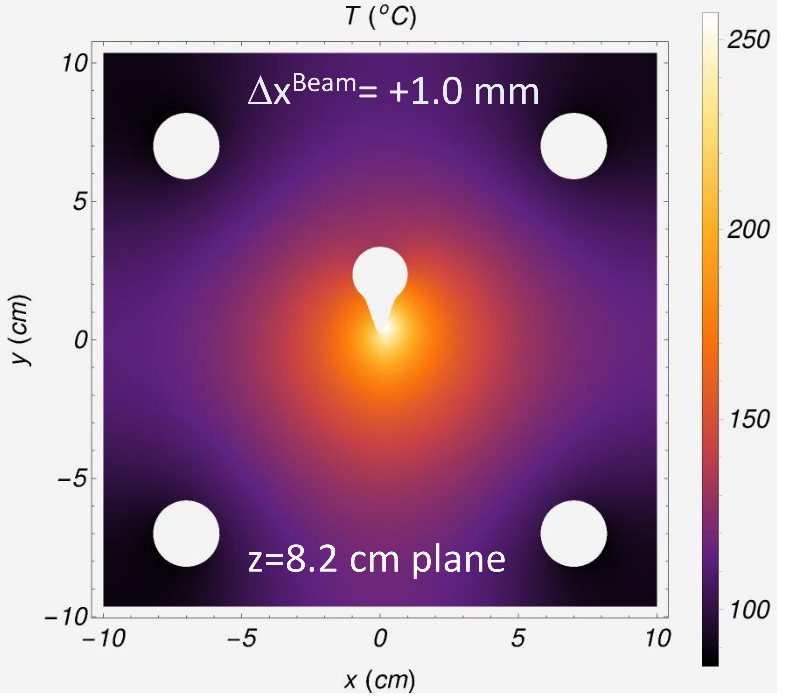
Check with a Fine Rectangular Grid

All Nominal ($\sigma^{(x,y)}_{beam}$ = 1 mm, 4 holes)	Keyhole	0.13	+90	37	230	100	7
$\sigma^{(x,y)}_{beam}$ = 0.33 mm	Keyhole	0.1	+90	43	290	105	14
+0.5mrad angle in Y	Circular	0.15	+90	58	275	105	7
+1mm shift in X	Keyhole	0.5	+70	8.2	260	100	4

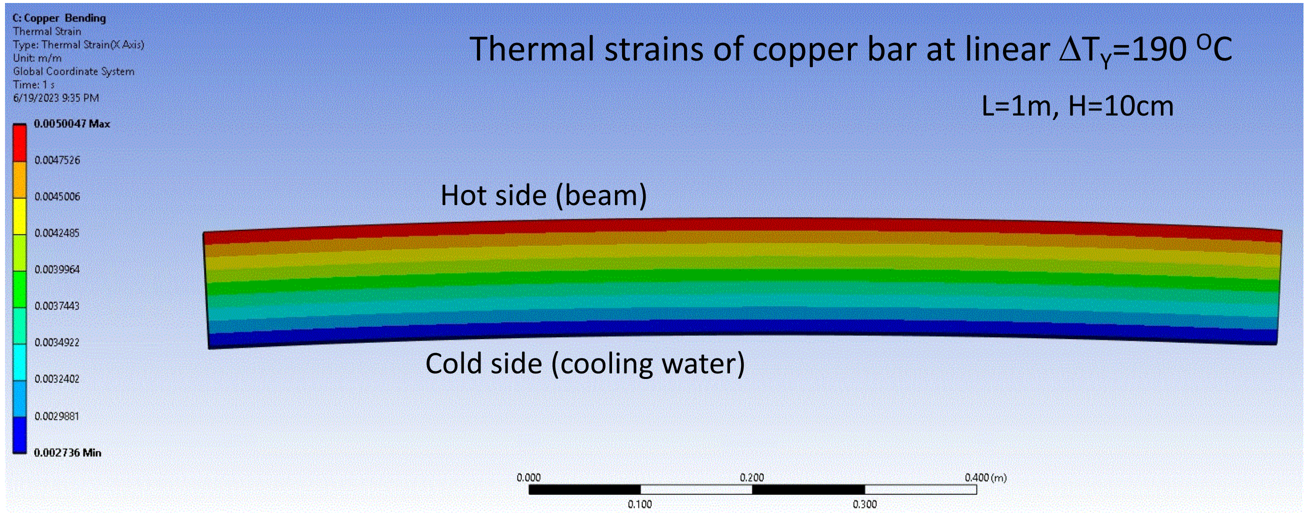
Potential Problems and Mitigations (Pavel)

- At very large vertical angles (500 μrad), the beam can penetrate deep into CPS and cause somewhat elevated temperatures (275 ^{O}C).
  - The radiation environment is probably not going to be affected much.
  - The photon beam position needs to be monitored and used in the beam interlock.
- At large horizontal shifts (~1 mm), the beam can impact the upstream wall of the absorber missing the keyhole and thus cause high temperatures (300 ^{O}C).
  - The radiation environment is probably not going to be affected much.
  - Beam position need to be monitored and beam needs to be shut off at large excursions.





Thermal Deformations



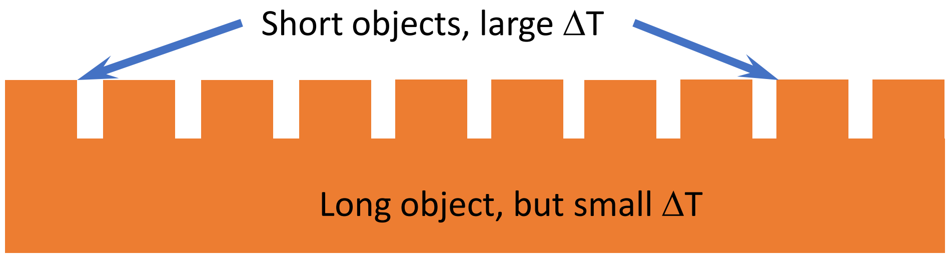
- Assume uniform and isotropic copper absorber not attached to anything.
- Thermal strain for uniform isotropic body is $\varepsilon = \alpha \cdot \Delta T$.
  - Assume that such a displacement actually occurs.
- With an approximation for the curvature radius $r \approx \frac{H}{\alpha \Delta T}$, and for the sagitta $s = r - \sqrt{r^2 - \frac{L^2}{4}} \approx \frac{\alpha}{8} \cdot \Delta T \cdot \frac{L^2}{H}$, assuming $\alpha \approx 1.674 \cdot 10^{-5} \frac{1}{K}$, we get that:

  a) At L = 94 cm, H=10 cm, ΔT= 150 ^{0}C , $s \approx$ 2.8 mm .
     - Sagitta is almost as large as a third of the photon beam channel!

  b) At L = 229 cm, H=10 cm, ΔT= 100 ^{0}C , $s \approx$ 11.0 mm .
     - Sagitta is larger than the whole beam channel!

  c) At L = 94 cm, H= 5 cm, ΔT= 30 ^{0}C , $s \approx$ 1.1 mm .
     - We may need to have shorter than one-meter-long absorber segments along the beam.
     - The temperature change over the long part of the absorber should be $\Delta T <$ 30 ^{0}C.

  d) At L = 10 cm, H= 5 cm, ΔT= 500 ^{0}C , $s \approx$ 0.2 mm .
     - We may need to have ~5 cm high and 10 cm long slits every 10 cm to avoid large deformation in the high temperature areas.



- These concepts needs to be properly modeled and calculated in ANSYS.

Thermal stresses

- Assume uniform and isotropic copper absorber not attached to anything.
- Thermal strain for uniform isotropic body is $\varepsilon = \alpha\Delta T$.
- Thermal stresses for uniform isotropic body are
  - $\sigma_{norm} = E \cdot \varepsilon = \alpha \cdot E \cdot \Delta T$ for normal stresses,
  - $\sigma_{sheer} = G \cdot \varepsilon = \alpha \cdot G \cdot \Delta T$ for sheer stresses.
- For copper :
  - $\sigma_{max}^{Y} \approx 283 \cdot 10^6$ Pa, $\sigma_{max}^{T} \approx 350 \cdot 10^6$ Pa ; $\alpha \approx 1.674 \cdot 10^{-5} \frac{1}{\mathrm{K}}$; $G \approx 4.4 \cdot 10^{10}$ Pa and $E \approx 12.6 \cdot 10^{10}$ Pa.
  - These constant depend on the type of the copper used.
    - Using Tim's numbers, where available.
  - Maximum allowed temperature differences for these numbers would be :
    - $\Delta T = 134$ ^{O}C / 166 ^{O}C for normal stress,
    - $\Delta T = 384$ ^{O}C / 475 ^{O}C for sheer stress.
  - Both of our CPS models can avoid $\Delta T = 384$ ^{O}C temperature differences across the absorber by monitoring and controlling the beam conditions.
    - Normal thermal stresses are not expected to be large
- There may be nothing we need to do to avoid excessive thermal stresses in the CPS models if there are no compression stresses involved.
  - This needs to be checked with ANSYS realistic model.
  - Mechanical stresses can be induced.
  - Normal stresses can also be present.
  - Even the presence of excessive stresses does not mean failure
    - CPS mechanical models need to be solved to determine the behavior of the absorber at given temperature and boundary conditions.

Conclusions

- Both models provide acceptable temperatures assuming care is taken when designing the absorber.
  - Pavel's model $T_{max} \approx 300\ ^{O}C$ for reasonably possible beam conditions.
  - Vitaly's model $T_{max} \approx 150\ ^{O}C$ for reasonably possible beam conditions.
  - Deformations and thermal stresses are highly unlikely to be serious problems.
    - Proper design for the absorber and mounting will be needed.
- Radiation is another environment is another important criteria for the CPS design
  - The desired goal is to have PDE on the level of 25 rem/h in the tagger hall, as indicated in the PAC proposal.
    - This is not a new goal, see e-mail from December 7, 2022, in the JLAB "mailman" archive.
      - https://mailman.jlab.org/pipermail/halld-cps/2022-December/000004.html
  - Activation dose after 1000-hour continuous beam operations and 1 hour break needs to be low enough for a controlled access into the hall.
- I would like to decide on the CPS model before next Monday meeting.
  - Still need FLUKA data on beam size and beam background.
  - Need to have the material weights for Tim to estimate the cost for models.