Active Collimator Temperature with a 20% Radiator

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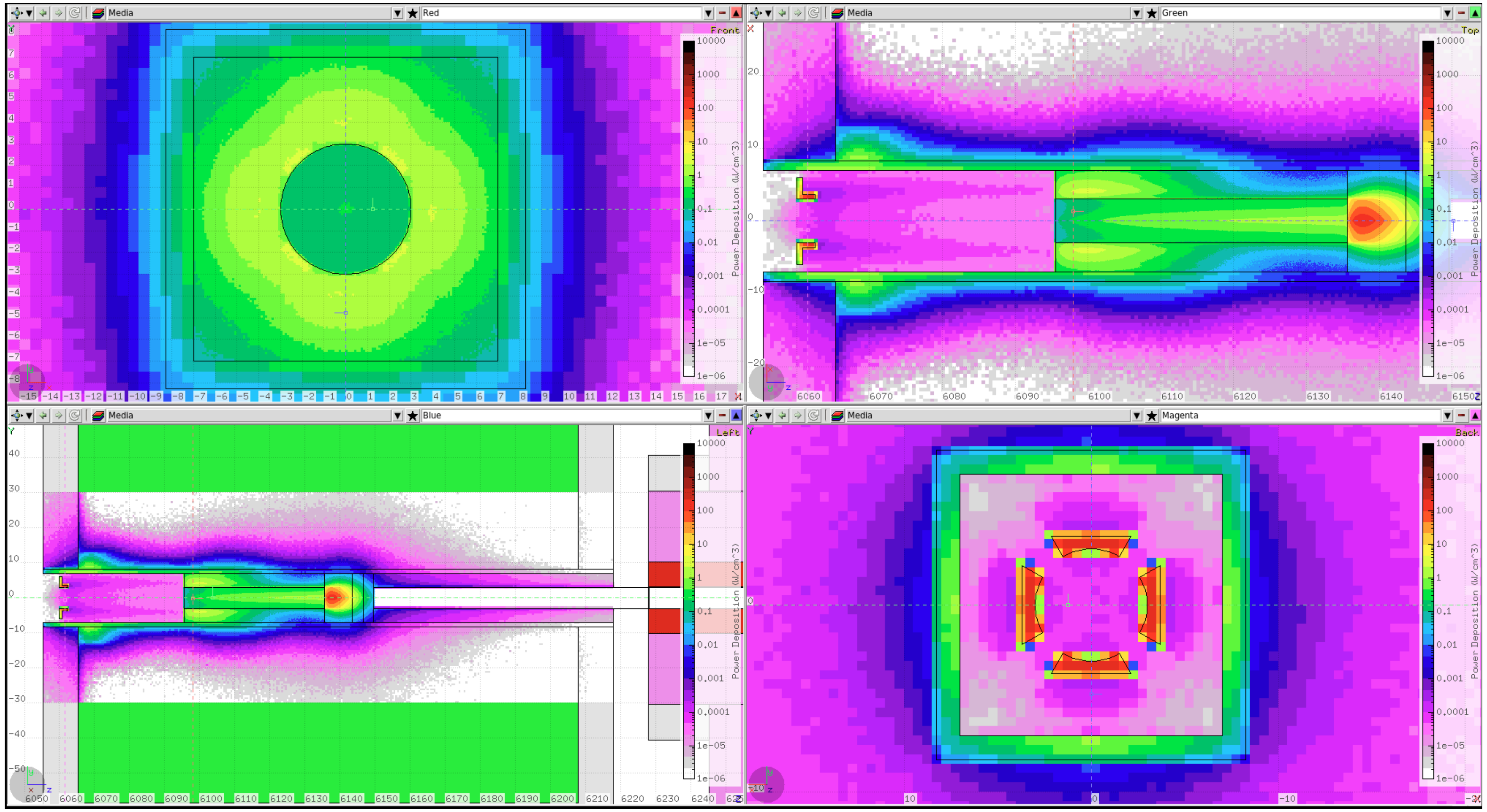
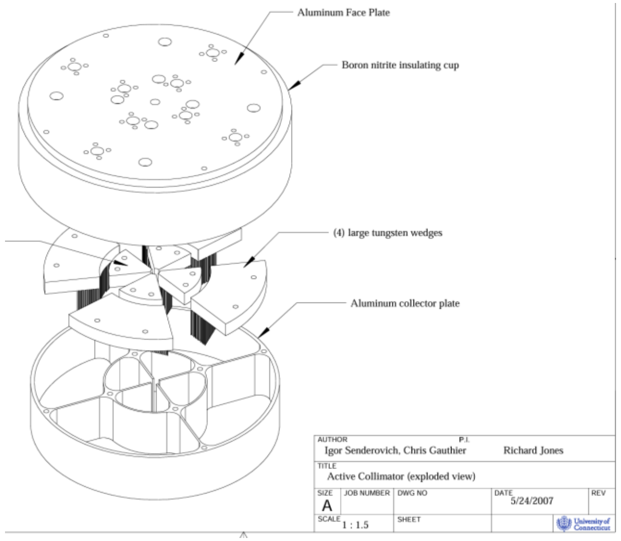
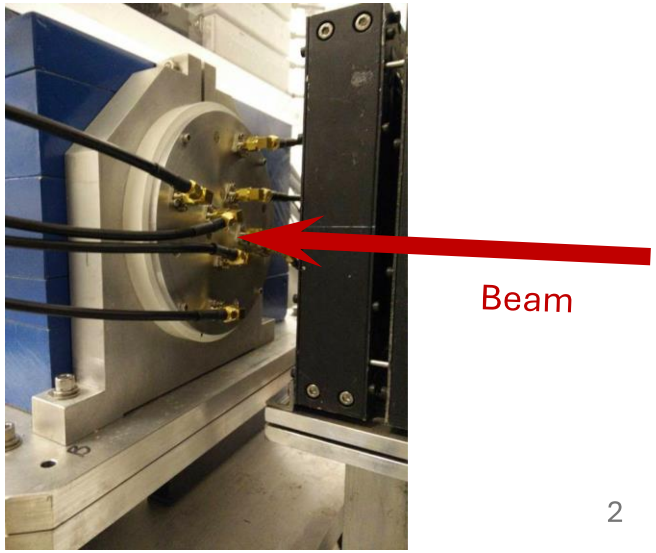
FLUKA Data

- Use FLUKA power deposition map for a 20% radiator to estimate the temperatures in the Active Collimator, Be-target and W-plug with nominal γ-beam positions.
- Tungsten in AC collimator has aperture of D=6cm
  - 90W is absorbed in each AC wedge.
  - Power deposited in the cooper around Be-target is reduced by ~400W.
- AC can be cooled
  - With water through the outer edges through boron nitride cup.
  - With forced air via the aluminum backplate and via the boron nitride cup.
  - We need to avoid contact with aluminum back-plate and the collector plate as to not distort AC signals.
- Boron Nitride is not isotropic
  - Manufacturer only provided a single number for thermal conductivity.
  - Unsure about the type of lattice of BN.
- Amount of power removed through the mounting of AC in the KPT assembly depends on the details of engineering design and cannot be evaluated at this time.





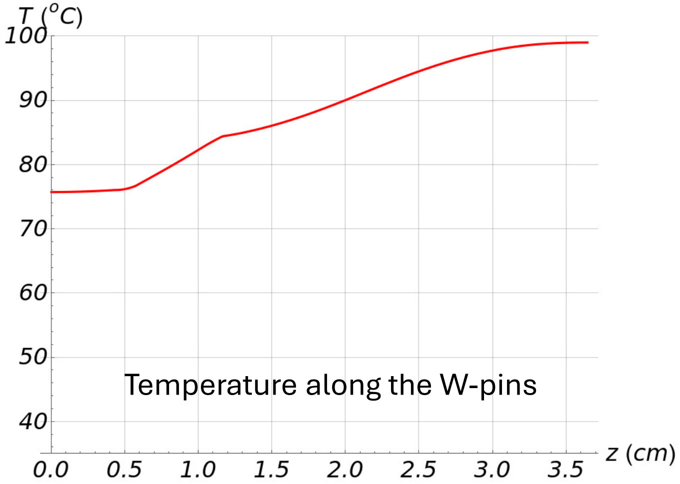


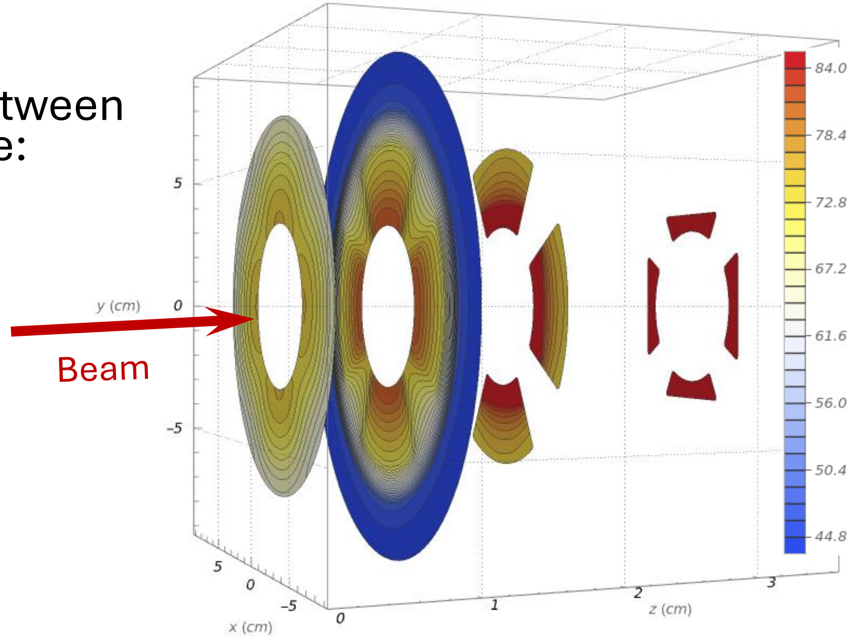
Water Cooled, Isotropic

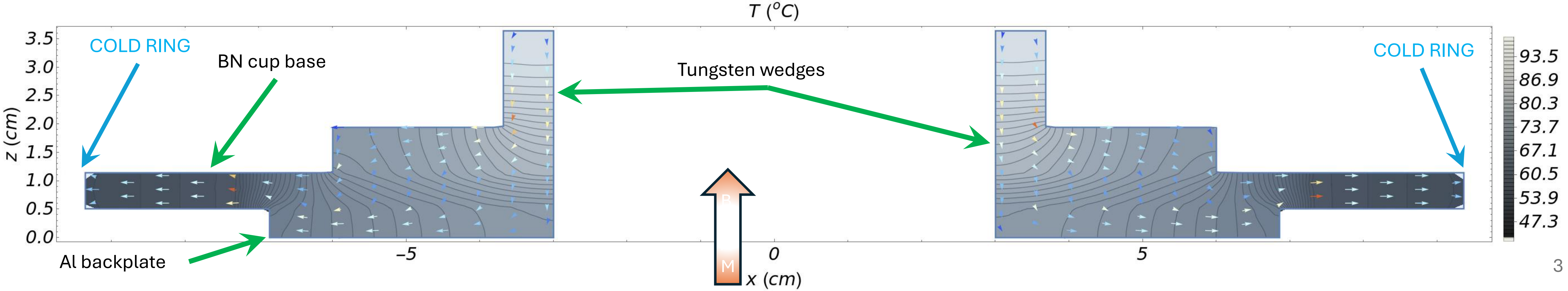
$$\vec{\nabla}\cdot\left(\kappa(\vec{x})\cdot\vec{\nabla}T(\vec{x})\right)=p(\vec{x})$$

- Model AC geometry in Mathematica
  - W-wedges
  - Boron Nitride insulator cup
  - Al back-plate
  - Cu housing ring for cooling
  - Scalar thermal conductivity $\kappa(\vec{x})$:
    - 35 W/(m K) for BN-B (PDF document, mfr. site),
    - 146 W/(m K) for W,
    - 238 W/(m K) for Al,
    - 385 W/(m K) for Cu.
- Water cooling through the outer radius of the cooling ring.
  - Water average temperature T=35 ^{0}C .
  - Heat exchange coefficient for water is 5000 W/(K m^2).
  - No radiation or convection assumed.

- Temperature drop ΔT≈ 50 ^{0}C between the hotspot and cooling surface:
  - T_{max}~100 ^{0}C at the tip W-pins,
  - T_{Cu}~45 ^{0}C in Cu ring,
  - T_{Al}~75 ^{0}C in Al back-plate.





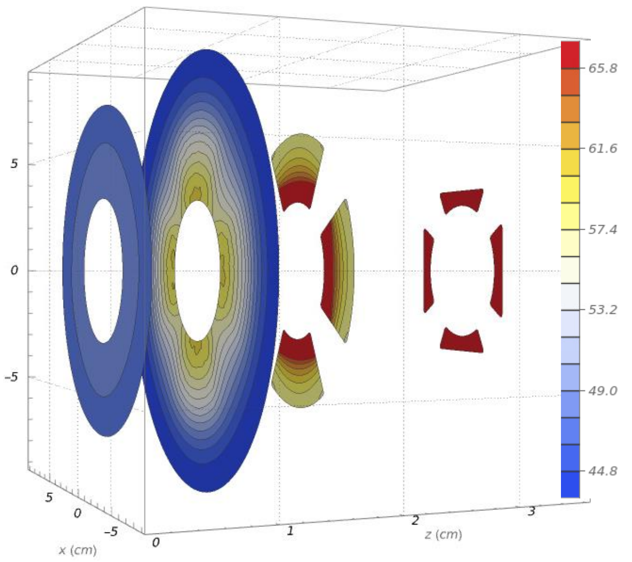


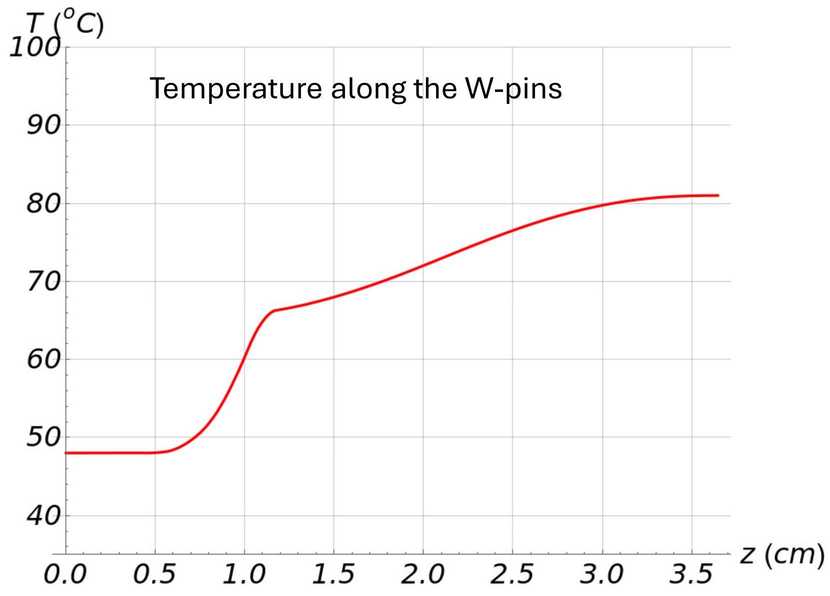
Water-cooled, Anisotropic, Axial

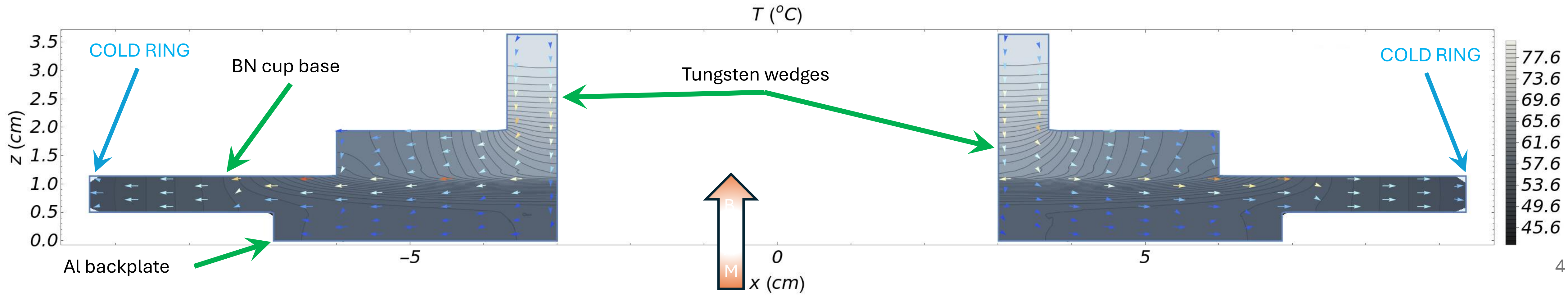
$$\vec{\nabla} \cdot \left(\kappa(\vec{x}) \cdot \vec{\nabla} T(\vec{x}) \right) = p(\vec{x})$$

$$\kappa(\vec{x}) = \begin{bmatrix} \kappa_r(\vec{x}) & 0 & 0 \\ 0 & \kappa_r(\vec{x}) & 0 \\ 0 & 0 & \kappa_z(\vec{x}) \end{bmatrix}$$

- Thermal conductivity is a diagonal tensor with three components ($\kappa_r, \kappa_r, \kappa_z$)
  - For BN ceramics they are (400, 400, 4) W/(m K), taken from some article found on the web.
  - For other materials, the thermal conductivity is a unit tensor times the thermal conductivity.
    - 146 W/(m K) for W,
    - 238 W/(m K) for Al,
    - 385 W/(m K) for Cu.
- Water cooling through the outer radius of the cooling ring.
  - Water average temperature T=35 ^{0}C .
  - Heat exchange coefficient for water is 5000 W/(K m^2).
  - No radiation or convection assumed.
- Temperature drop ΔT≈ 38 ^{0}C between the hotspot and cooling surface:
  - T_{max}~81 ^{0}C at the tip W-pins,
  - T_{Cu}~43 ^{0}C in Cu ring,
  - T_{Al}~48 ^{0}C in Al back-plate.

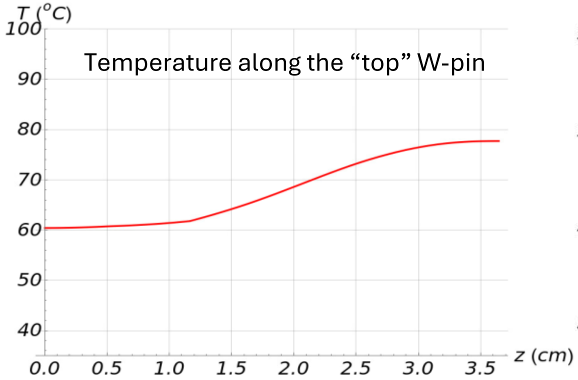


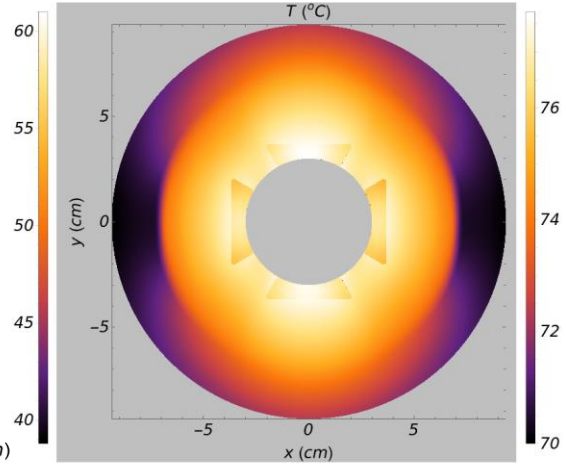


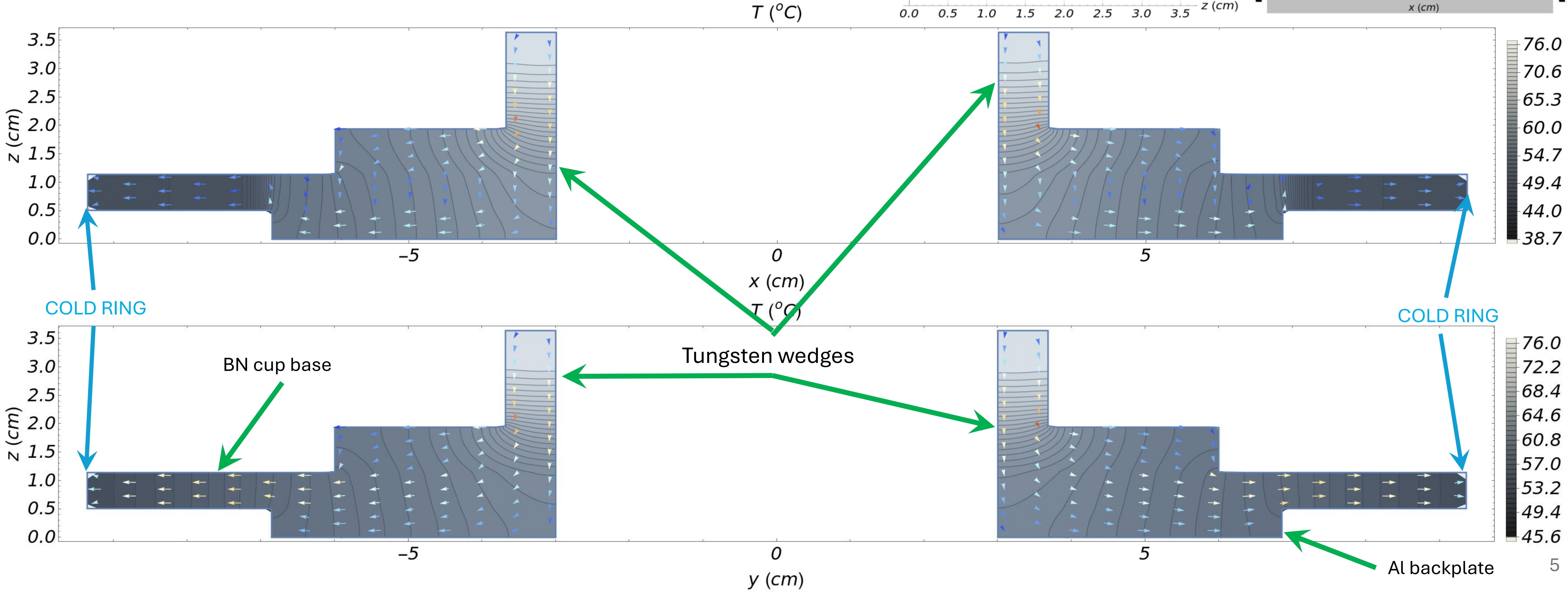


Water-cooled, Anisotropic, Transverse

- Assume "bad" conductivity in the x-direction.
- Use parameters as in the axial case and solve the equation.
- Temperatures are low, T_{max}~78 ^{0}C at the tip W-pins, even lower than for the axial case.
    - Not sure of the thermal conductivity tensor from the article really applies to our BN cup.



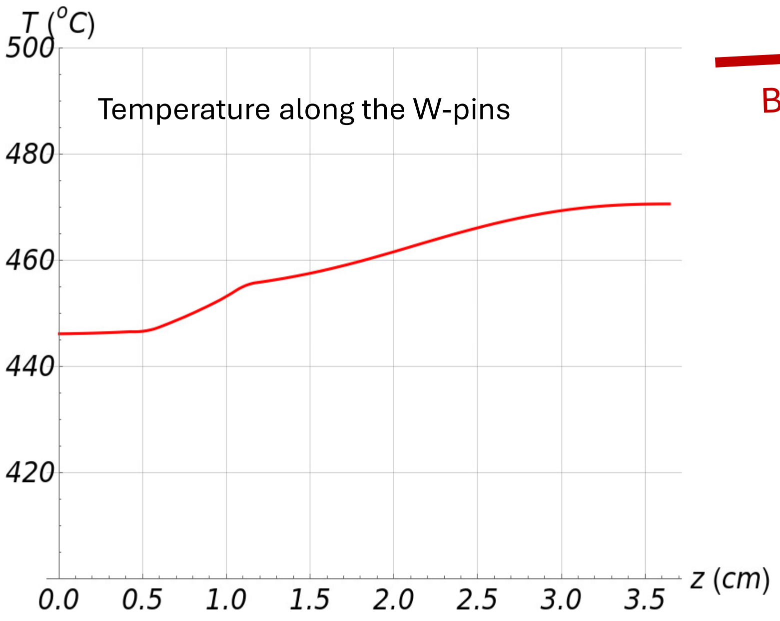


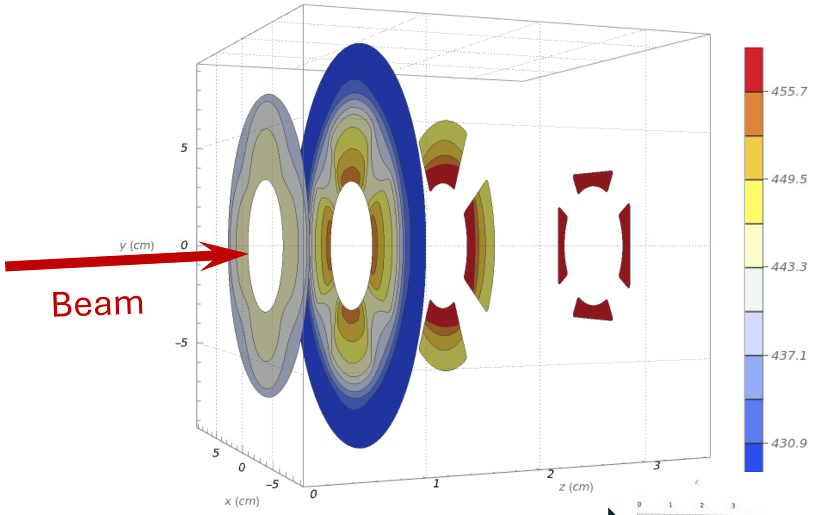


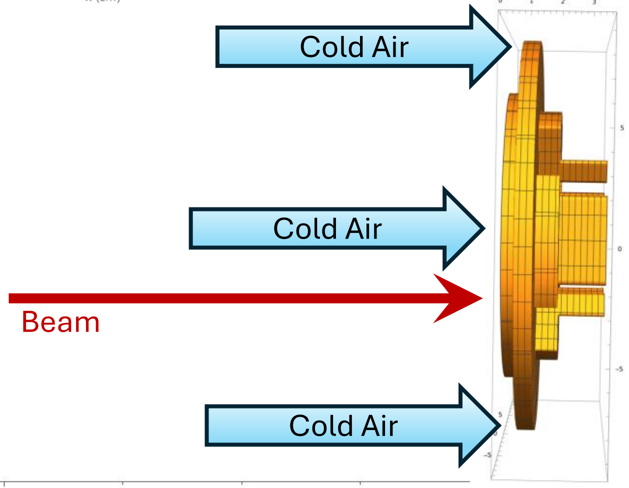
Air-cooled, Isotropic

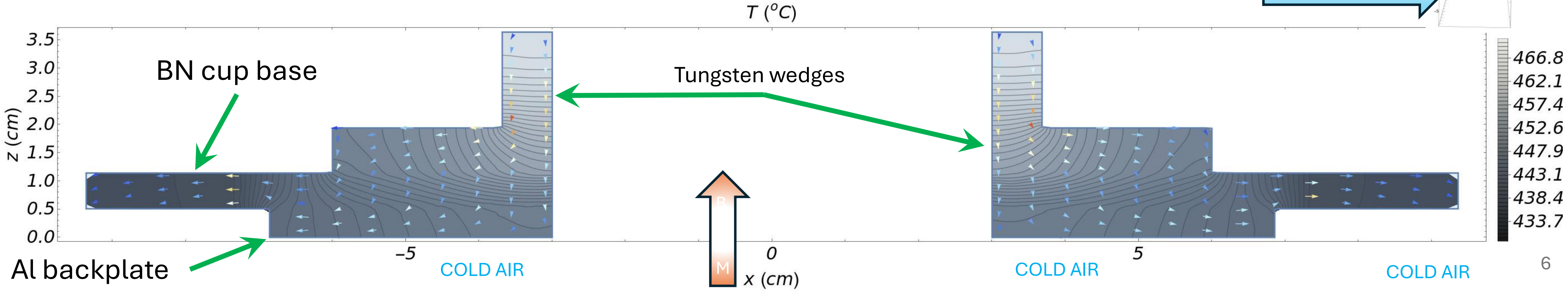
$$\vec{\nabla} \cdot \left(\kappa(\vec{x}) \cdot \vec{\nabla} T(\vec{x}) \right) = p(\vec{x})$$

- Forced air cooling through the upstream surface of BN cup, and Al back-plate, and upstream and side face of copper ring, .
  - Air with average temperature T=20 ^{0}C .
  - Heat exchange coefficient for air is 20 W/(K m^2) .
    - Not sure about this number.
  - No other modes of power dissipation assumed.
- Temperature drop $\Delta T \approx 40$ ^{0}C between the hotspot and cooling surface:
  - T_{max}~475 ^{0}C at the tip W-pins,
  - T_{Cu}~445 ^{0}C in Cu ring,
  - T_{Al}~435 ^{0}C in Al back-plate.
- The back-plate surface will become hot >400 ^{0}C.
  - Heat flow through the mounting surface to the bulk of KPT assembly will reduce the temperature.
  - If heat exchange coefficient is lower, then the temperature will be higher.



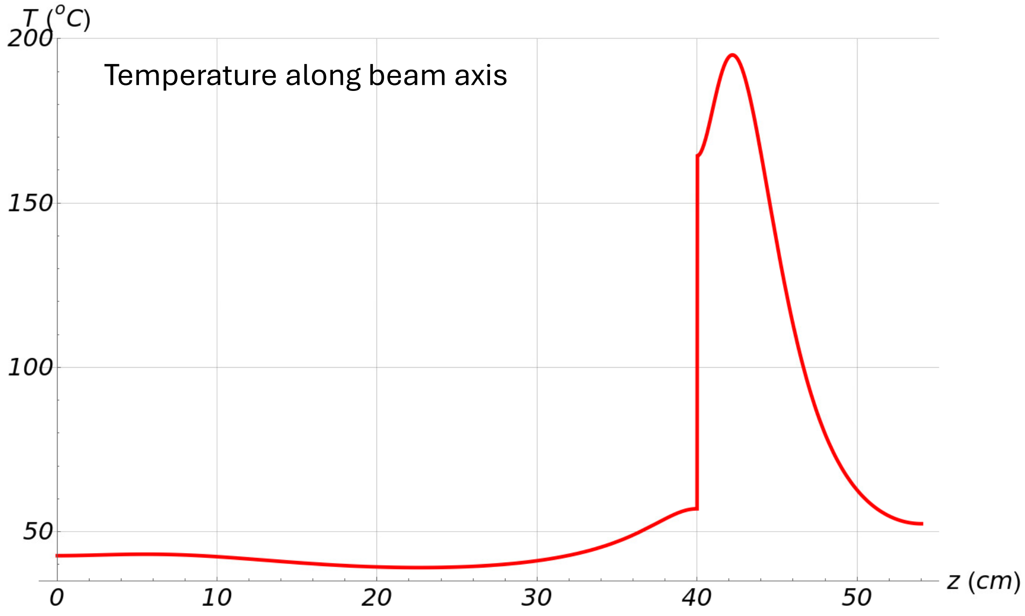


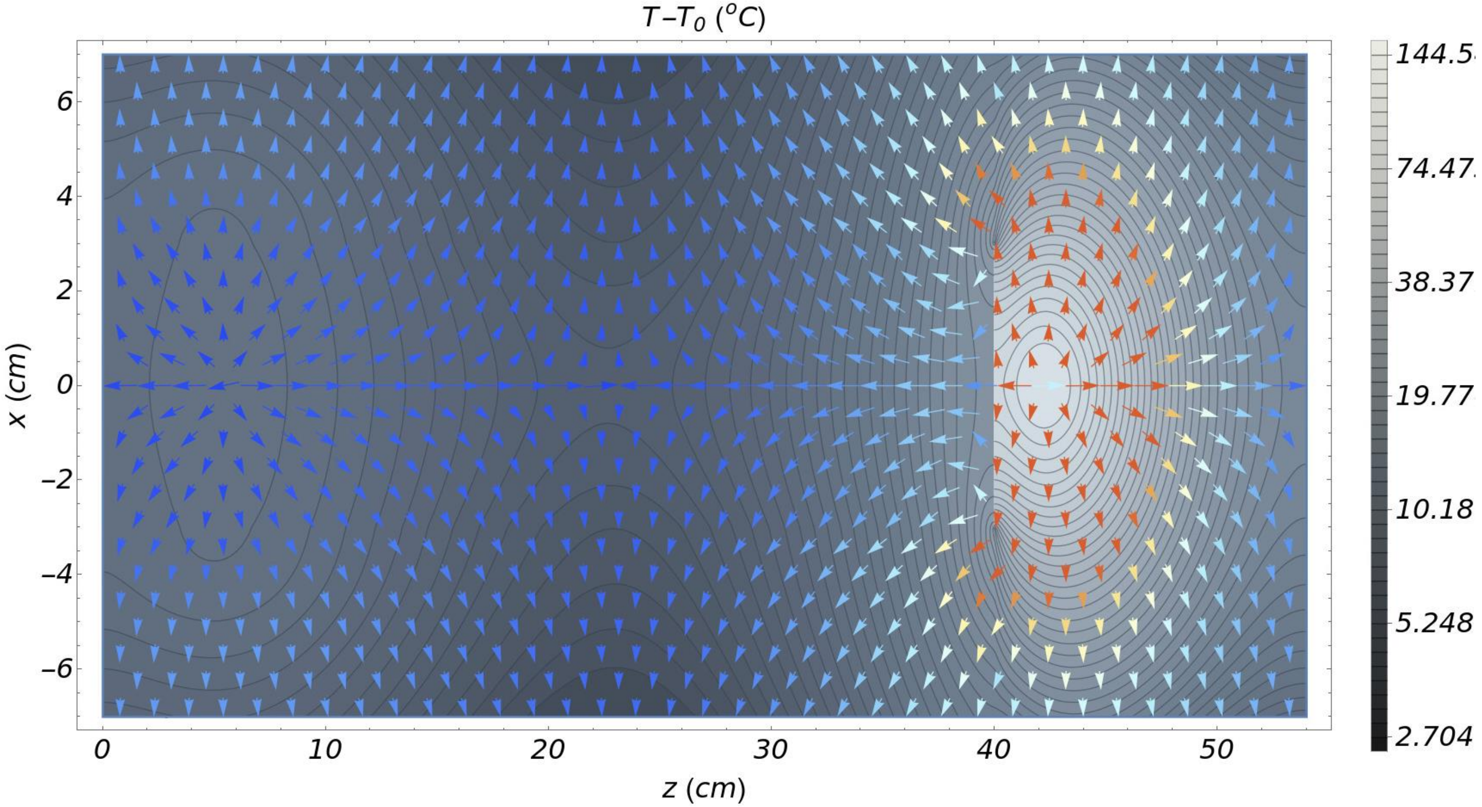




Be-target and W-plug Temperature

- Used the same Mathematica notebook as I did for last week
  - Cooling from four sides with water at average temperature T_0=35 ^{0}C.
- Not much difference observed in the temperature distribution near the KPT target due to adding AC to FLUKA geometry.





- Not much difference observed in the temperature distribution near the KPT target due to adding AC to FLUKA geometry.
- Tungsten plug temperature is the same as without AC, T_{max}=195 ^{0}C.
  - Water temperature at the surface may reach T_{ws}=55 ^{0}C .
- Be-target T_{max}=43 ^{0}C, decreased by ~2 ^{0}C.
  - ~400 Wats taken by AC from the copper around Be-target.

Conclusions

- Active collimator used with a 20% radiator can be water-cooled from radial periphery of BN cup.
  - The temperatures of AC with active cooling look OK for thermal conductivity values considered here.
  - The temperature distribution depends on the thermal conductivity of Boron Nitride ceramic cup.
  - Need to get the specifications for the BN cup from the manufacturer to predict the AC temperature.
- With only forced air cooling, the temperatures in AC can get quite high.
  - Heat transfer to the support structure may help, not evaluated here.
- Temperatures around the Be-target are OK, assuming modified configuration of Be-target.

- There does not seem to be a serious problem with high temperatures when using a 20% radiator in CPS with nominal beam positions at KPT.
  - The design of the KPT cooling system will need significant modifications to work with a with 20% radiator.
  - Consider using copper plates instead of aluminum for AC.
  - Photon beam excursions from the nominal positions at KPT may produce higher temperatures.