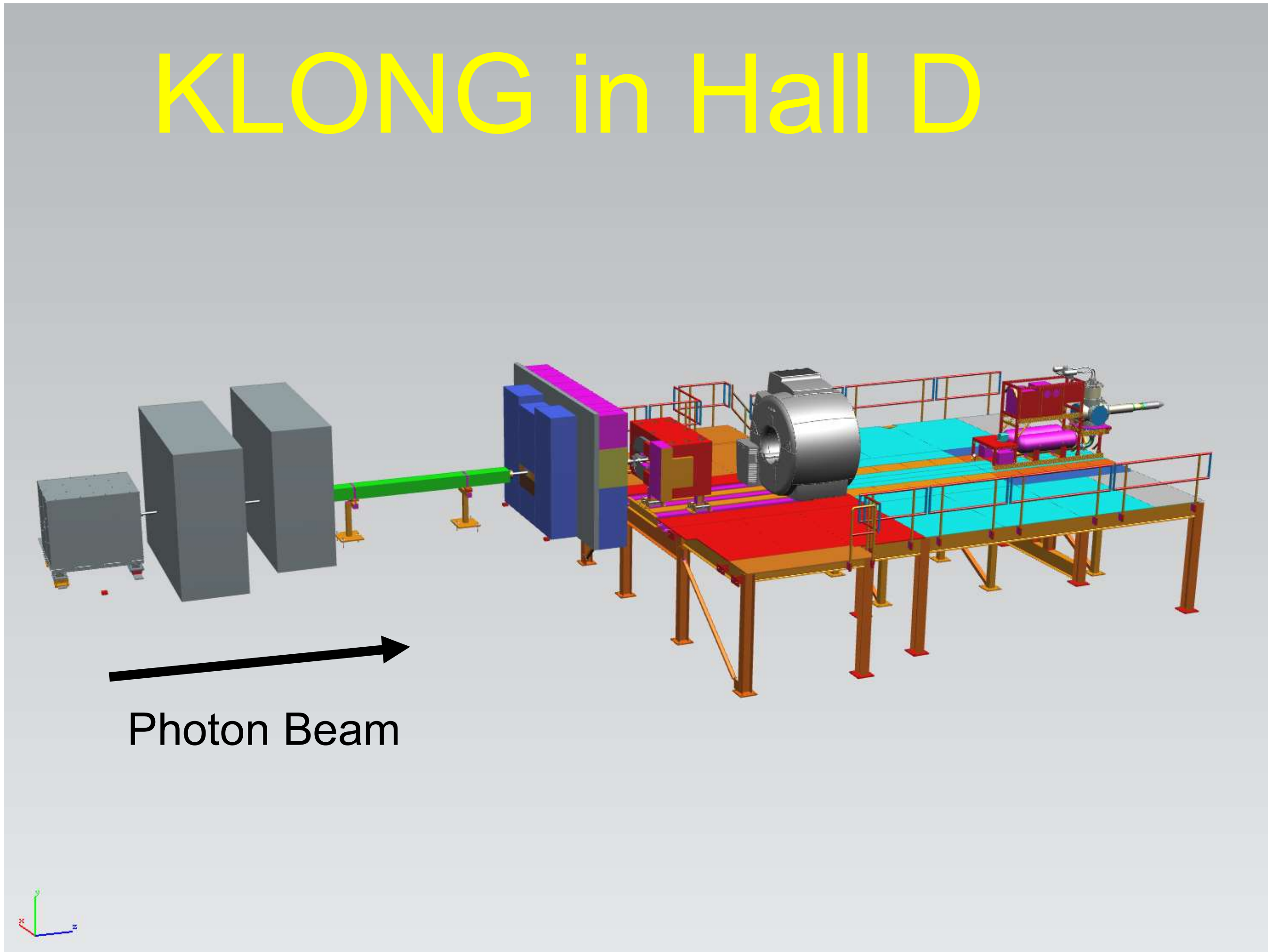
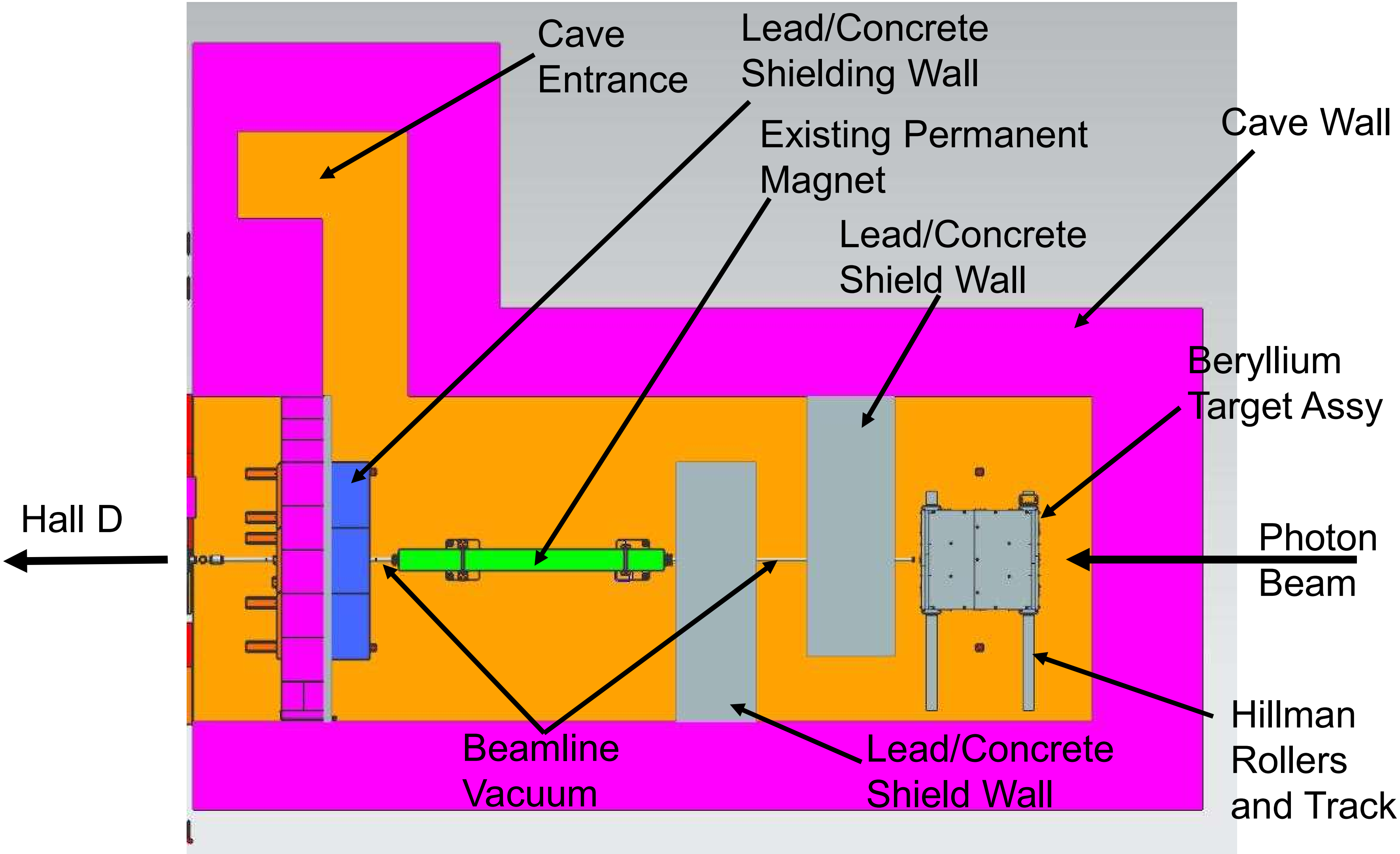
# Engineering Update



KLF Collaboration Meeting May 2022 - Engineering Update - Presented by Tim Whitlatch

# Hall D Collimator Cave Layout



Cave Entrance

Lead/Concrete Shielding Wall

Existing Permanent Magnet

Lead/Concrete Shield Wall

Cave Wall

Beryllium Target Assy

Hall D

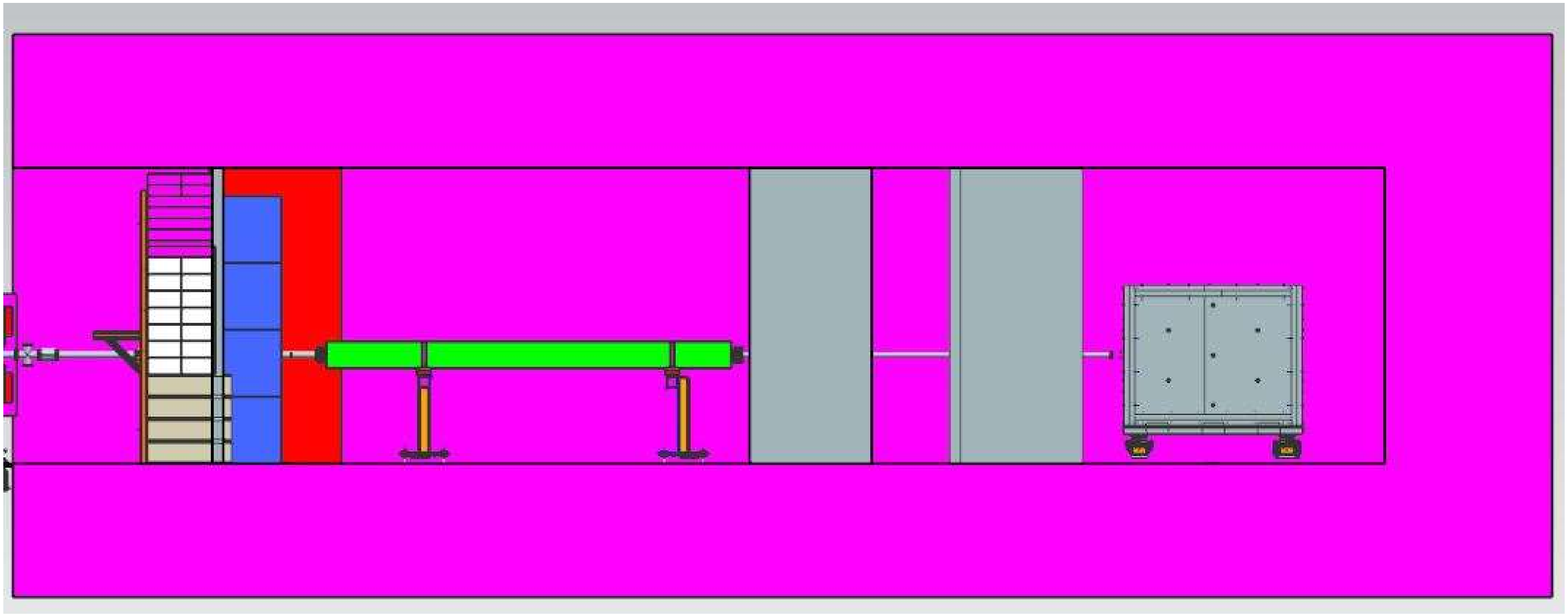
Photon Beam

Hillman Rollers and Track

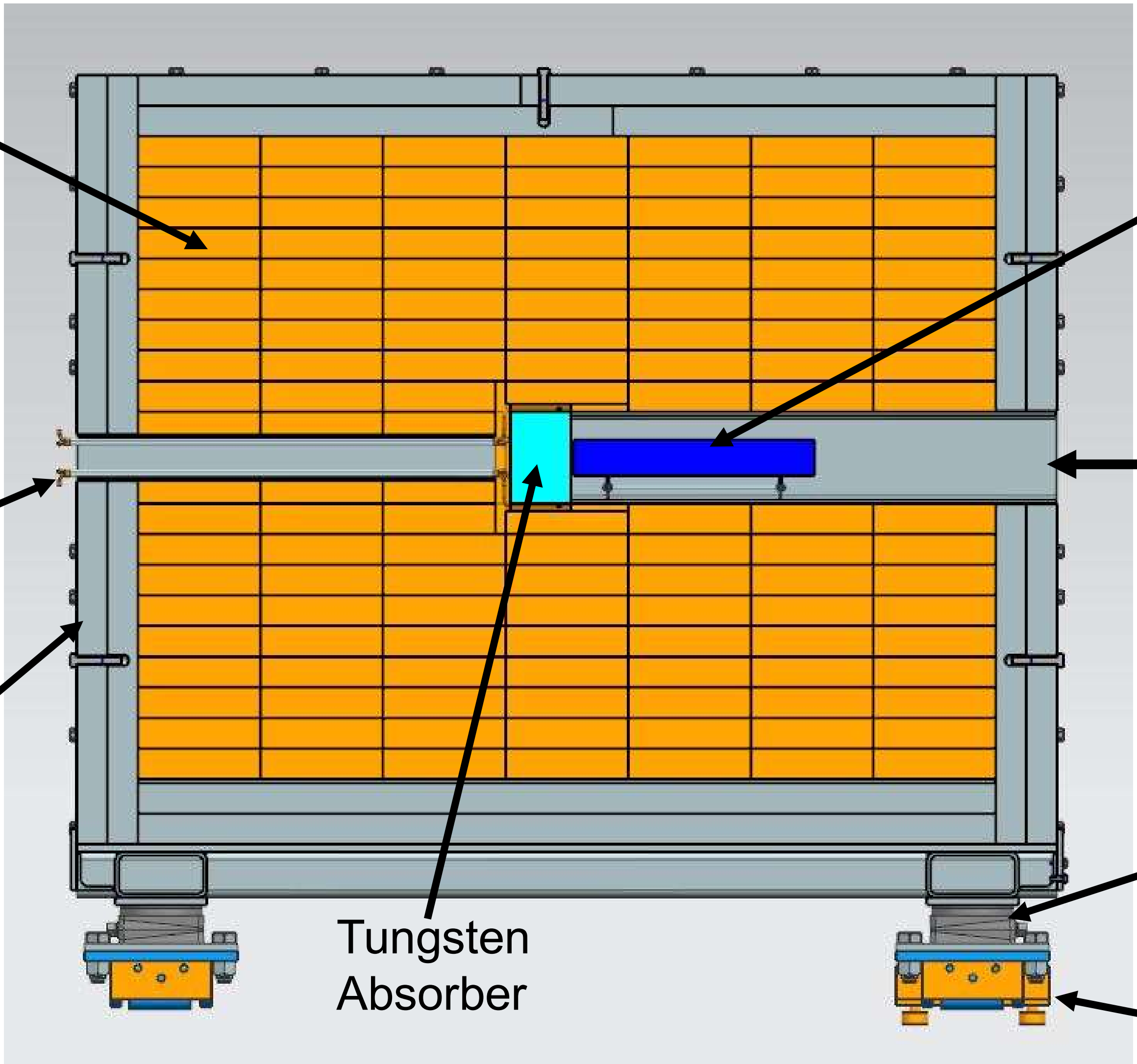
Beamline Vacuum

Lead/Concrete Shield Wall

# Cave Layout Elevation



# Beryllium Target Assy



Lead Brick Shielding

Beryllium Target

Photon Beam

Cooling Tubes

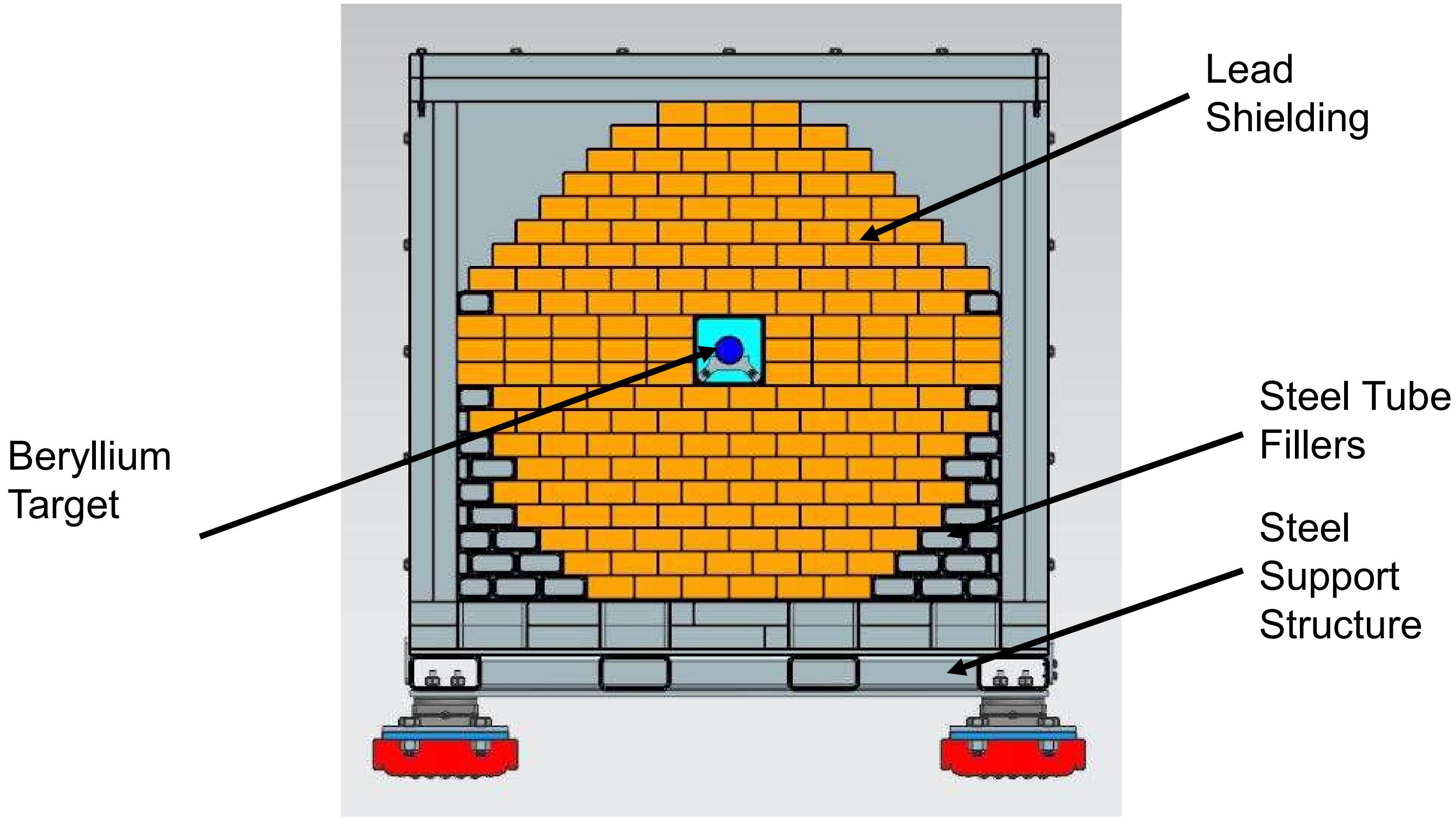
Borated Poly Shield

Wedge Levelers

Tungsten Absorber

Hillman Rollers

# Beryllium Target Section



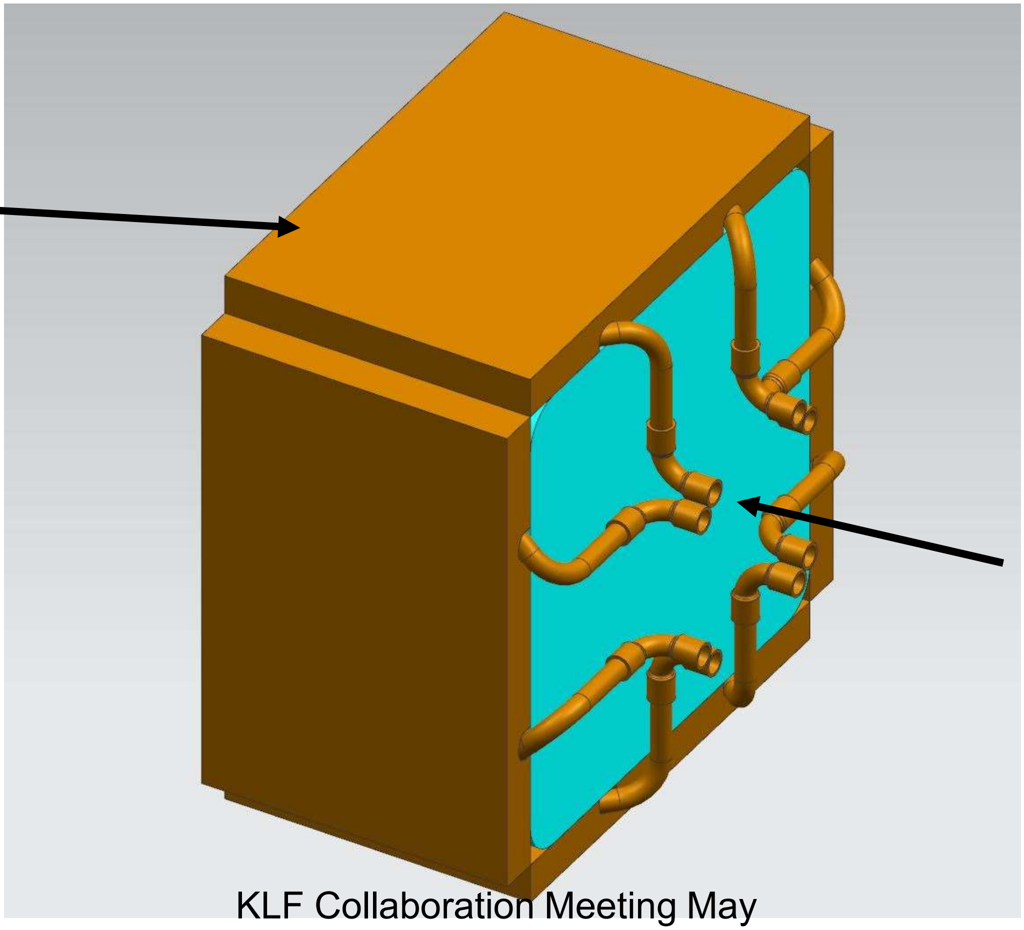
# Design Requirements/Specs

- Berylium Target
  - 6cm diameter
  - 40 cm length
  - 500W power absorption
  - Max Temperature 400C (factor of 3 to melting)
  - Air cooled
- Tungsten absorber
  - 15cm square
  - 10cm length
  - 5.2KW power absorption
  - Max Temperature inside 1000C (factor of 3 to melting)
  - Water cooled – separate LCW system required

# Tungsten Absorber Thermal Analysis

- Power absorption data provided by Vitaly Baturin
- Modelled in ANSYS Static Thermal
- Shows maximum delta T of 216C
- Outer Surface cooled with water under 100C
- Maximum Tungsten Temp 316C

# 3D Rendering - cooling plates on 4 sides - Max water temp less than 100C



Copper cooling plates

Copper cooling tubes

# Cooling Water removing 6KW from Tungsten

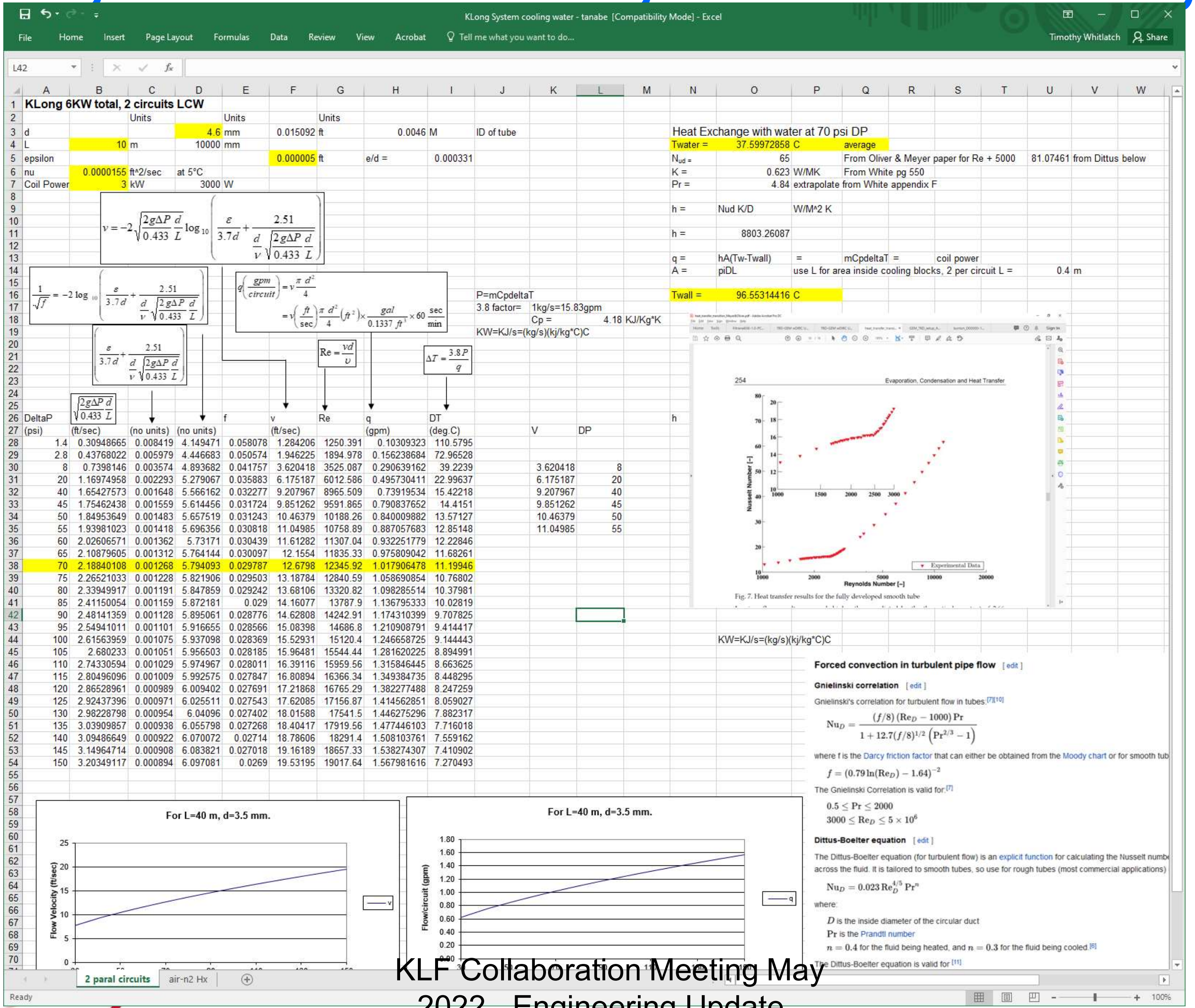


Fig. 7. Heat transfer results for the fully developed smooth tube

**KLong 6KW total, 2 circuits LCW**

| | | Units | | Units | | Units | | | |
|---|---|---|---|---|---|---|---|---|---|
| d | | | 4.6 | mm | 0.015092 | ft | 0.0046 | M | ID of tube |
| L | 10 | m | 10000 | mm | | | | | |
| epsilon | | | | | 0.000005 | ft | e/d = | 0.000331 | |
| nu | 0.0000155 | ft^2/sec | at 5°C | | | | | | |
| Coil Power | 3 | kW | 3000 | W | | | | | |

$$v = -2\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}\log_{10}\left(\frac{\varepsilon}{3.7d}+\frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left(\frac{\varepsilon}{3.7d}+\frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$q\left(\frac{gpm}{circuit}\right) = v\frac{\pi d^2}{4} = v\left(\frac{ft}{sec}\right)\frac{\pi d^2}{4}\left(ft^2\right)\times\frac{gal}{0.1337\ ft^3}\times 60\ \frac{sec}{min}$$

$$\left(\frac{\varepsilon}{3.7d}+\frac{2.51}{\frac{d}{\nu}\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}}\right)$$

$$\mathrm{Re} = \frac{vd}{\upsilon}$$

$$\Delta T = \frac{3.8P}{q}$$

P=mCpdeltaT
3.8 factor= 1kg/s=15.83gpm
Cp = 4.18 KJ/Kg*K
KW=KJ/s=(kg/s)(kj/kg*C)C

| DeltaP (psi) | $\sqrt{\frac{2g\Delta P}{0.433}\frac{d}{L}}$ (ft/sec) | (no units) | (no units) | f | v (ft/sec) | Re | q (gpm) | DT (deg.C) | V | DP |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.4 | 0.30948665 | 0.008419 | 4.149471 | 0.058078 | 1.284206 | 1250.391 | 0.10309323 | 110.5795 | | |
| 2.8 | 0.43768022 | 0.005979 | 4.446683 | 0.050574 | 1.946225 | 1894.978 | 0.156238684 | 72.96528 | | |
| 8 | 0.7398146 | 0.003574 | 4.893682 | 0.041757 | 3.620418 | 3525.087 | 0.290639162 | 39.2239 | 3.620418 | 8 |
| 20 | 1.16974958 | 0.002293 | 5.279067 | 0.035883 | 6.175187 | 6012.586 | 0.495730411 | 22.99637 | 6.175187 | 20 |
| 40 | 1.65427573 | 0.001648 | 5.566162 | 0.032277 | 9.207967 | 8965.509 | 0.73919534 | 15.42218 | 9.207967 | 40 |
| 45 | 1.75462438 | 0.001559 | 5.614456 | 0.031724 | 9.851262 | 9591.865 | 0.790837652 | 14.4151 | 9.851262 | 45 |
| 50 | 1.84953649 | 0.001483 | 5.657519 | 0.031243 | 10.46379 | 10188.26 | 0.840009882 | 13.57127 | 10.46379 | 50 |
| 55 | 1.93981023 | 0.001418 | 5.696356 | 0.030818 | 11.04985 | 10758.89 | 0.887057683 | 12.85148 | 11.04985 | 55 |
| 60 | 2.02606571 | 0.001362 | 5.73171 | 0.030439 | 11.61282 | 11307.04 | 0.932251779 | 12.22846 | | |
| 65 | 2.10879605 | 0.001312 | 5.764144 | 0.030097 | 12.1554 | 11835.33 | 0.975809042 | 11.68261 | | |
| 70 | 2.18840108 | 0.001268 | 5.794093 | 0.029787 | 12.6798 | 12345.92 | 1.017906478 | 11.19946 | | |
| 75 | 2.26521033 | 0.001228 | 5.821906 | 0.029503 | 13.18784 | 12840.59 | 1.058690854 | 10.76802 | | |
| 80 | 2.33949917 | 0.001191 | 5.847859 | 0.029242 | 13.68106 | 13320.82 | 1.098285514 | 10.37981 | | |
| 85 | 2.41150054 | 0.001159 | 5.872181 | 0.029 | 14.16077 | 13787.9 | 1.136795333 | 10.02819 | | |
| 90 | 2.48141359 | 0.001128 | 5.895061 | 0.028776 | 14.62808 | 14242.91 | 1.174310399 | 9.707825 | | |
| 95 | 2.54941011 | 0.001101 | 5.916655 | 0.028566 | 15.08398 | 14686.8 | 1.210908791 | 9.414417 | | |
| 100 | 2.61563959 | 0.001075 | 5.937098 | 0.028369 | 15.52931 | 15120.4 | 1.246658725 | 9.144443 | | |
| 105 | 2.680233 | 0.001051 | 5.956503 | 0.028185 | 15.96481 | 15544.44 | 1.281620225 | 8.894991 | | |
| 110 | 2.74330594 | 0.001029 | 5.974967 | 0.028011 | 16.39116 | 15959.56 | 1.315846445 | 8.663625 | | |
| 115 | 2.80496096 | 0.001009 | 5.992575 | 0.027847 | 16.80894 | 16366.34 | 1.349384735 | 8.448295 | | |
| 120 | 2.86528961 | 0.000989 | 6.009402 | 0.027691 | 17.21868 | 16765.29 | 1.382277488 | 8.247259 | | |
| 125 | 2.92437396 | 0.000971 | 6.025511 | 0.027543 | 17.62085 | 17156.87 | 1.414562851 | 8.059027 | | |
| 130 | 2.98228798 | 0.000954 | 6.04096 | 0.027402 | 18.01588 | 17541.5 | 1.446275296 | 7.882317 | | |
| 135 | 3.03909857 | 0.000938 | 6.055798 | 0.027268 | 18.40417 | 17919.56 | 1.477446103 | 7.716018 | | |
| 140 | 3.09486649 | 0.000922 | 6.070072 | 0.02714 | 18.78606 | 18291.4 | 1.508103761 | 7.559162 | | |
| 145 | 3.14964714 | 0.000908 | 6.083821 | 0.027018 | 19.16189 | 18657.33 | 1.538274307 | 7.410902 | | |
| 150 | 3.20349117 | 0.000894 | 6.097081 | 0.0269 | 19.53195 | 19017.64 | 1.567981616 | 7.270493 | | |

Heat Exchange with water at 70 psi DP

| | | | | |
|---|---|---|---|---|
| Twater = | 37.59972858 | C | average | |
| $N_{ud}$ = | 65 | | From Oliver & Meyer paper for Re + 5000 | 81.07461 from Dittus below |
| K = | 0.623 | W/MK | From White pg 550 | |
| Pr = | 4.84 | extrapolate from White appendix F | | |
| h = | Nud K/D | W/M^2 K | | |
| h = | 8803.26087 | | | |
| q = | hA(Tw-Twall) | = | mCpdeltaT = | coil power |
| A = | piDL | use L for area inside cooling blocks, 2 per circuit L = | | 0.4 m |
| Twall = | 96.55314416 | C | | |

h

KW=KJ/s=(kg/s)(kj/kg*C)C

**Forced convection in turbulent pipe flow** [ edit ]

**Gnielinski correlation** [ edit ]

Gnielinski's correlation for turbulent flow in tubes:[7][10]

$$\mathrm{Nu}_D = \frac{(f/8)\,(\mathrm{Re}_D - 1000)\,\mathrm{Pr}}{1 + 12.7(f/8)^{1/2}\left(\mathrm{Pr}^{2/3} - 1\right)}$$

where f is the Darcy friction factor that can either be obtained from the Moody chart or for smooth tub

$$f = (0.79\ln(\mathrm{Re}_D) - 1.64)^{-2}$$

The Gnielinski Correlation is valid for:[7]

$$0.5 \le \mathrm{Pr} \le 2000$$
$$3000 \le \mathrm{Re}_D \le 5 \times 10^6$$

**Dittus-Boelter equation** [ edit ]

The Dittus-Boelter equation (for turbulent flow) is an explicit function for calculating the Nusselt numb across the fluid. It is tailored to smooth tubes, so use for rough tubes (most commercial applications)

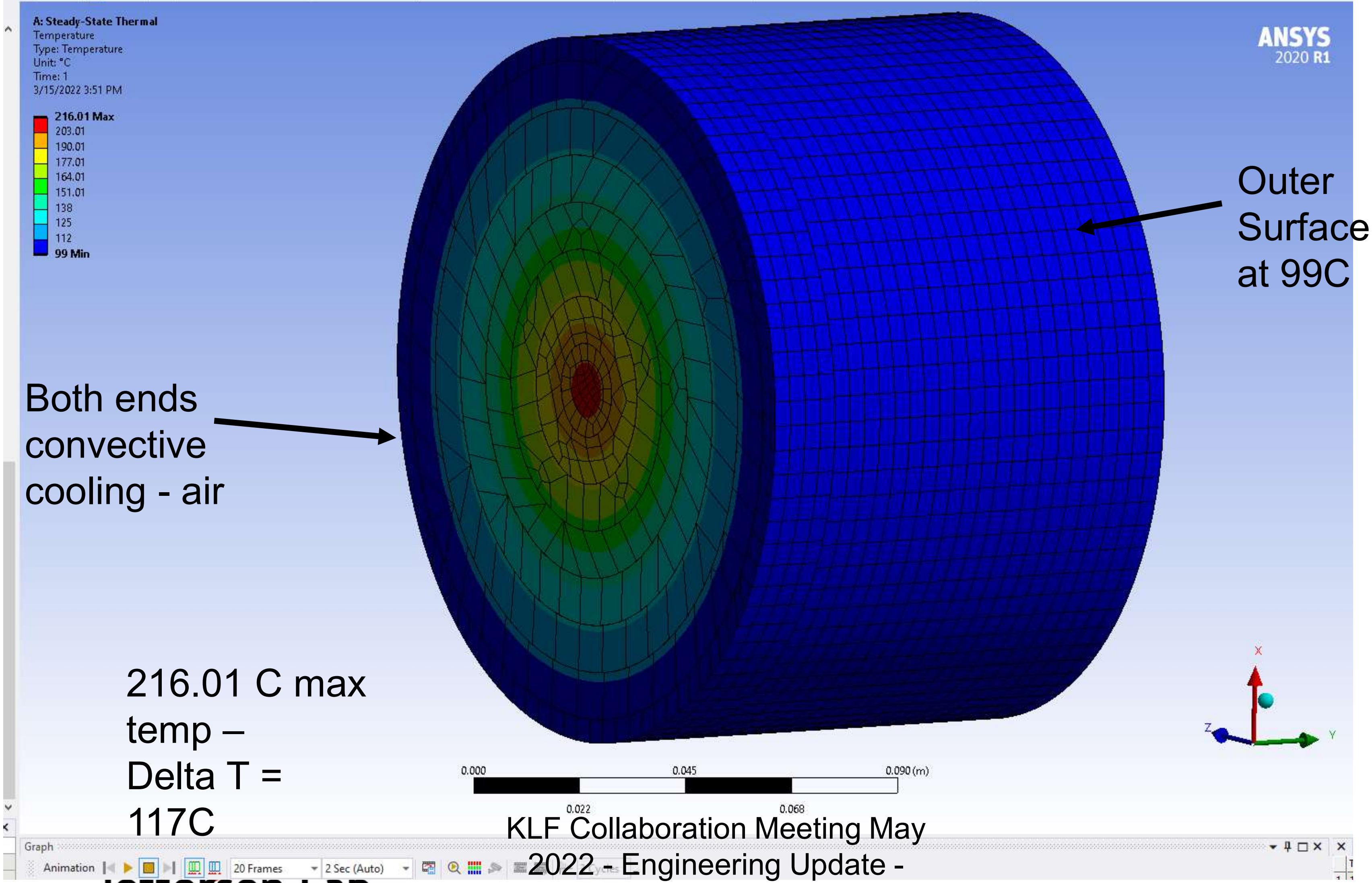
$$\mathrm{Nu}_D = 0.023\,\mathrm{Re}_D^{4/5}\,\mathrm{Pr}^n$$

where:

$D$ is the inside diameter of the circular duct
$\mathrm{Pr}$ is the Prandtl number
$n = 0.4$ for the fluid being heated, and $n = 0.3$ for the fluid being cooled.[6]

The Dittus-Boelter equation is valid for [11]

# 5.2 KW total input - 2 W/m^2 convection US face - 80C air temp



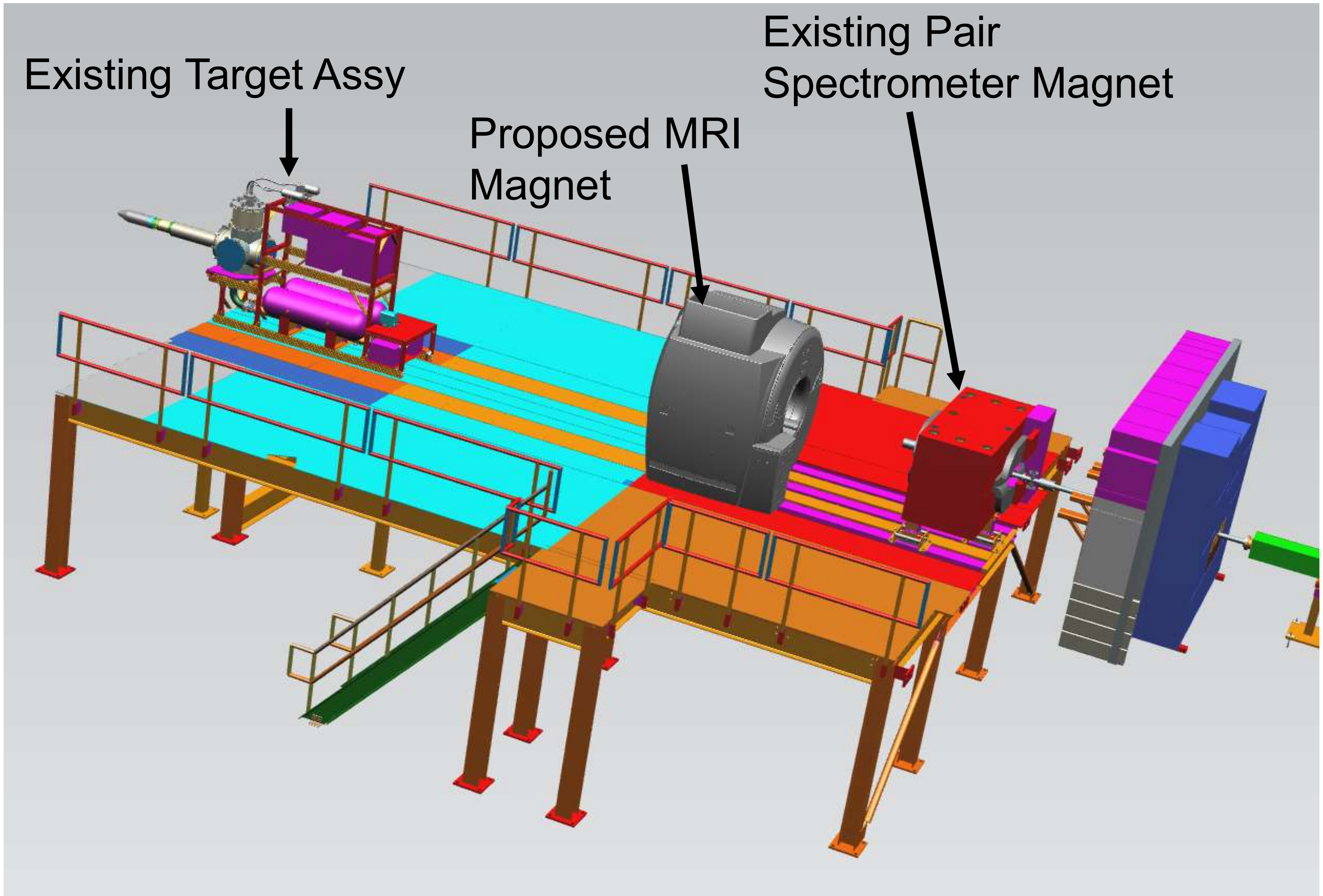
A: Steady-State Thermal
Temperature
Type: Temperature
Unit: °C
Time: 1
3/15/2022 3:51 PM

Outer Surface held at 99C

Both ends convective cooling - air

216.01 C max temp – Delta T = 117C

# Conceptual Setup in Hall D



# Status

- Collimator Cave Preliminary Drawings 90% Complete
- Thermal Analysis needed on Berylium
- Full Installation Plan Needed
- Beamline Requirements set
- Flux Monitor in Conceptual Phase – Proposed MRI will fit
- Separate meetings required for MRI Integration

# Backup