Conceptual Design of CPS for KLF

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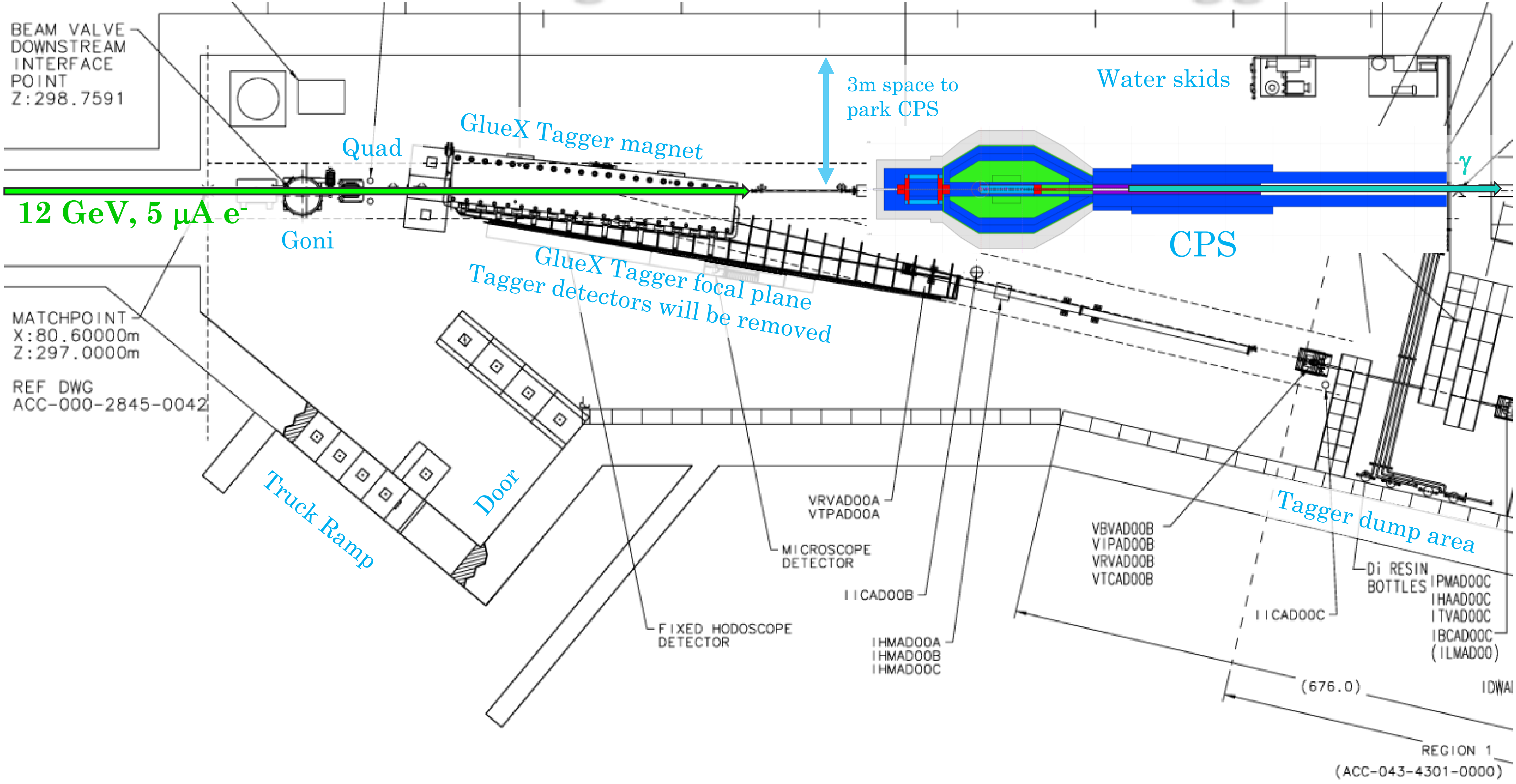
Overview

- Introduction
- Model Description
- Photon Beam from CPS
- Radiation Environment
- Temperature in CPS absorber
- Summary

CPS Positioning in the Hall D Tagger



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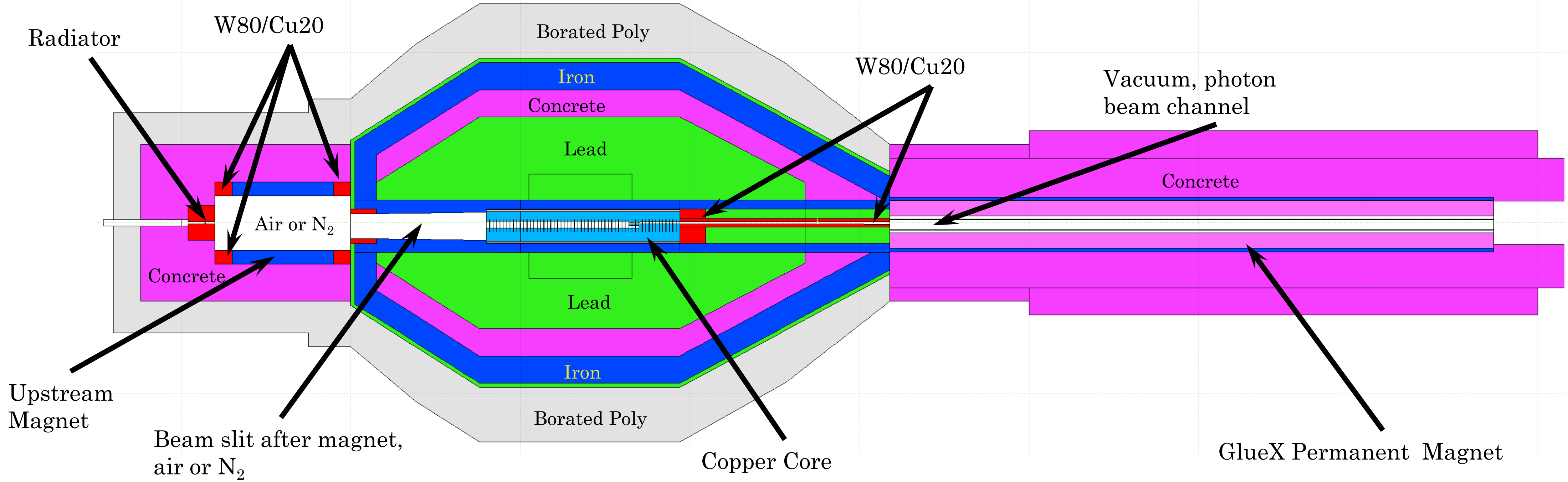
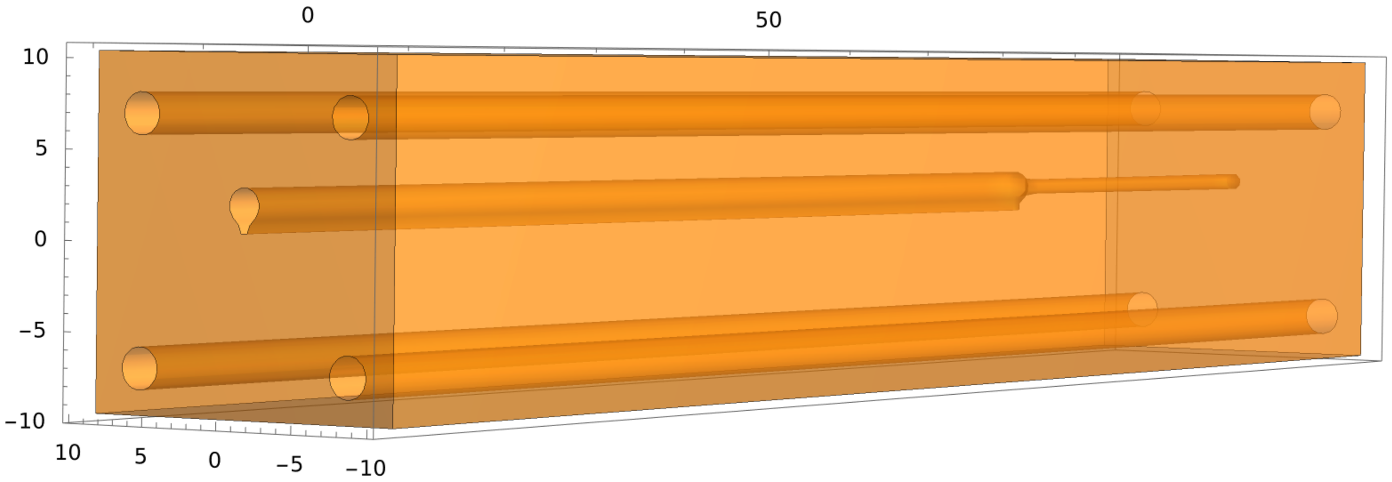
Current CPS Model

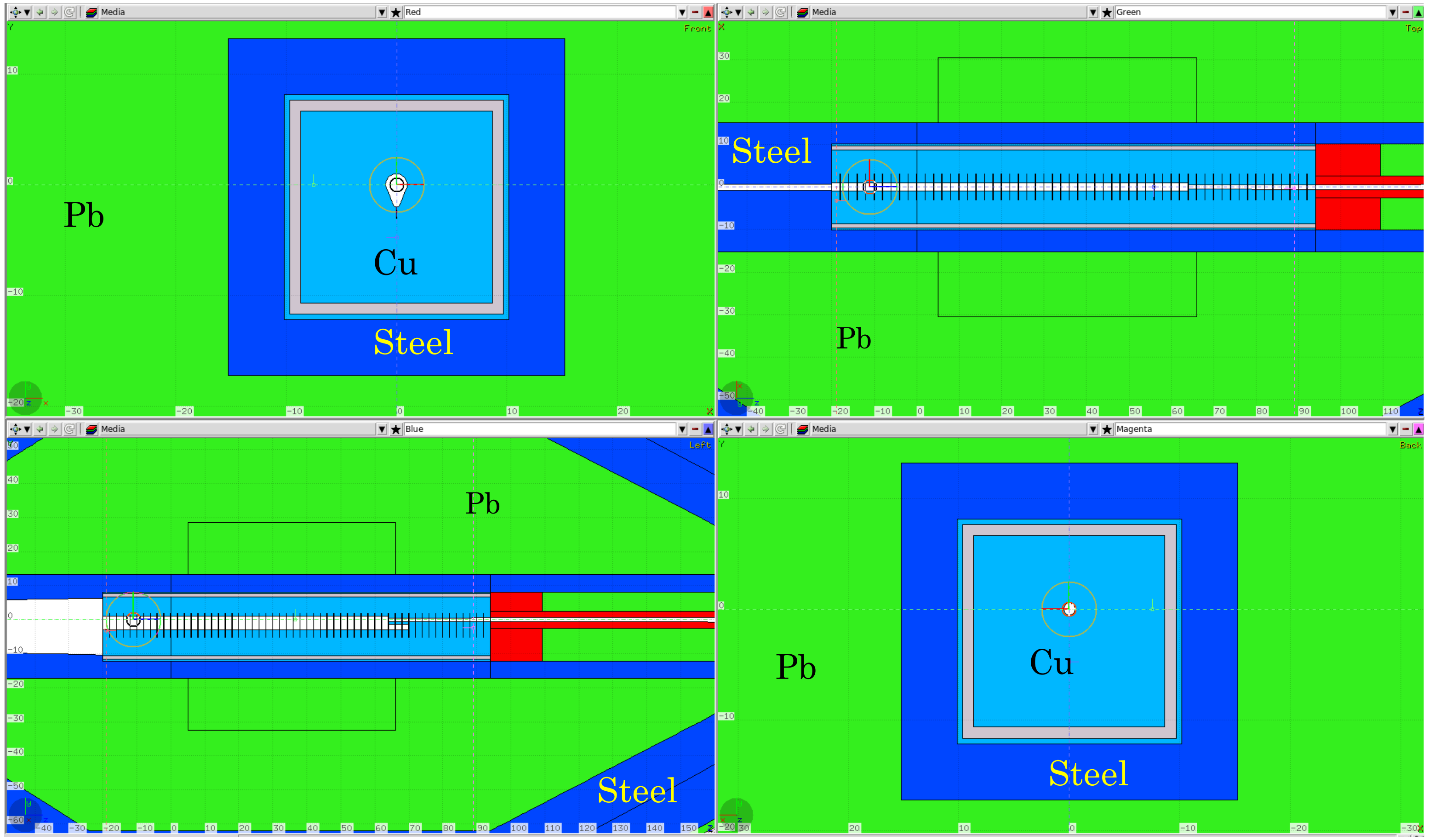
- Magnet and the absorber are separated by 0.8 meters.
  - No heat load on the magnet poles and coils from the core.
  - Low radiation exposure to the magnet.
- Clean-up magnet downstream for charged particles.
  - Utilize the existing permanent magnet used in GlueX beamline.
- No tungsten is used in the CPS shielding.
  - We save cost by using lead instead.
  - Small amount of a tungsten-copper mix is used for shielding the beam channel and magnet coils.
- Total estimated weight of CPS is approximately 75 metric tons.
  - Includes downstream beamline shielding.
  - Movable platform will add more weight.
  - Tagger Hall should easily handle CPS weighing 100 tons.
  - Estimated cost of the current design is ~$1.1M for CPS
  - Upstream beamline instrumentation will be extra.
- Tim discussed some of the engineering aspects in detail.



CPS Absorber

- Copper core with dimensions of 20cm x 20cm x 114cm.
  - To absorb and dissipate the power from the beam.
  - Copper is not ferromagnetic and is a very good heat conductor.
- Varying size beam channel to trap the secondary particles from the electromagnetic shower.
  - Wider cavity upstream for trapping electrons and EM shower remnants.
  - Narrow conical channel with diameter ~1cm for outgoing photons.
- Cooling channels for water flow capable of evacuating ~54 kW power.
- Copper absorber is surrounded by air, steel, and W/Cu mix.
  - No direct contact with lead.





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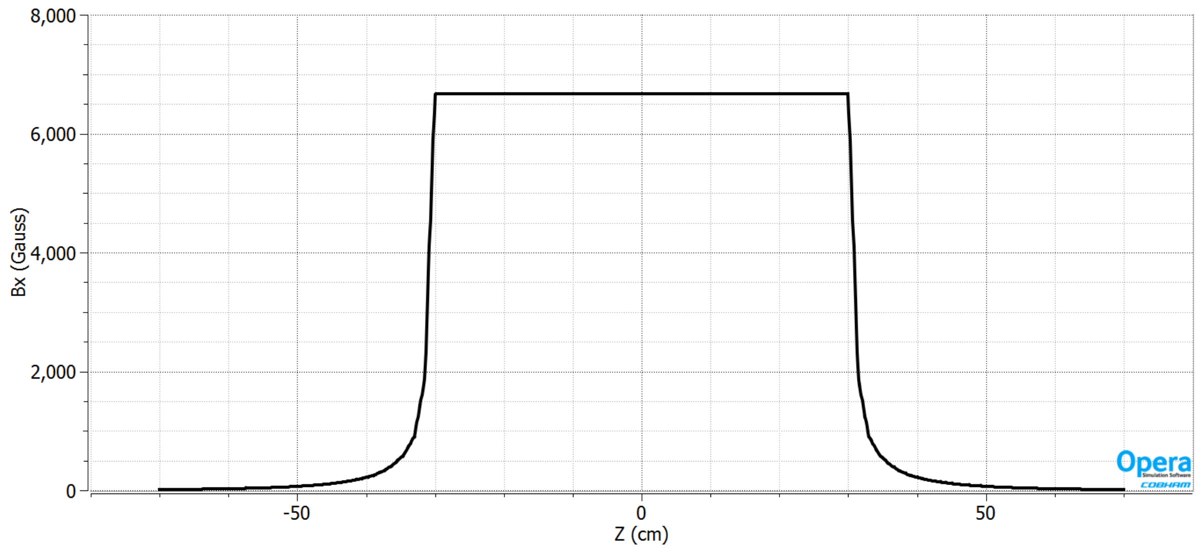
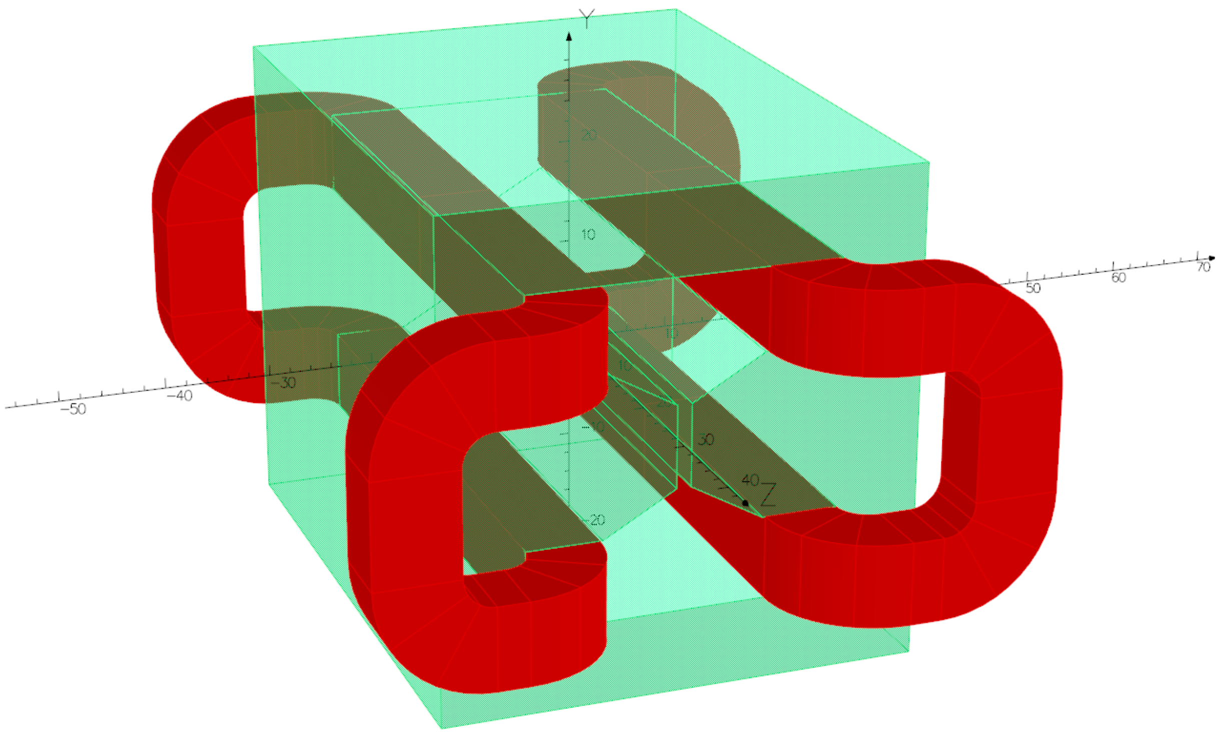
Upstream Magnet

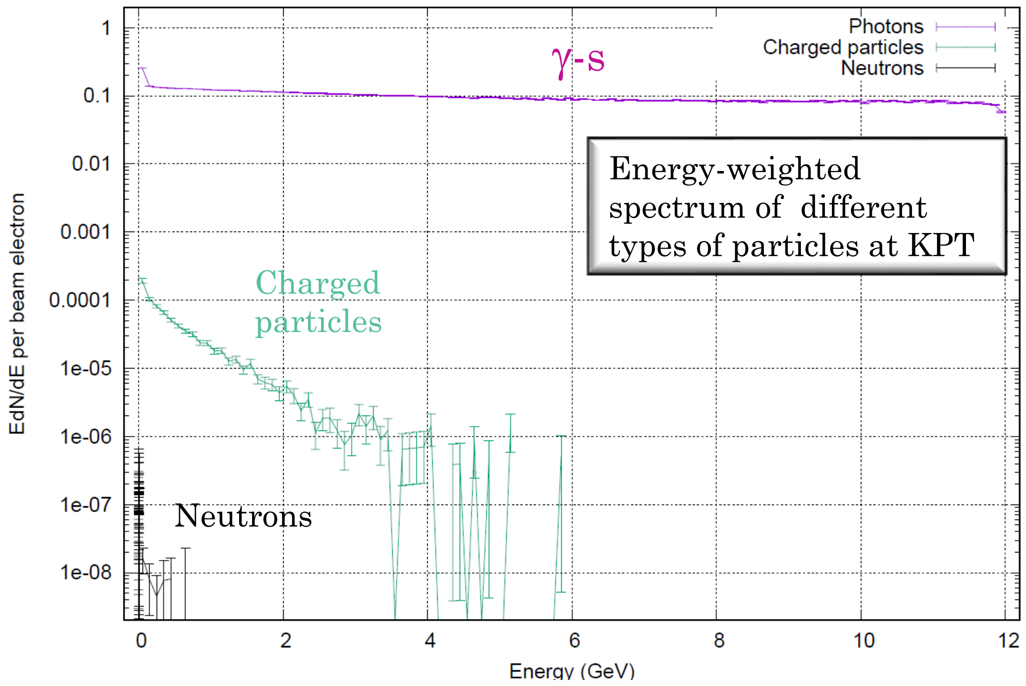
- Current CPS design requires ~0.4 T·m magnetic field in the x-direction.
- We developed a draft model of the magnet.
  - Magnet has 60 cm long coils.
  - Bedstead shape of coils for less radiation exposure.
  - The closest distance from coils to the beam center is ~11cm.
- The gap should be on the order 1 cm or more to avoid interaction with beam tails and halo.
  - Current design assumes 1.4 cm gap.
- Iron yoke with 8 cm thickness.
  - Total length of the yoke is 60cm
  - The transverse size of the yoke is 46cm x 48 cm.
- Chamfered iron poles.
- We used OPERA to calculate the field in the model.
  - The model can provide a dipole field of 0.67 T at 67 A/cm^2 current density in the coils.
    - Should be able to use Tagger Magnet power supply.
  - The field in the yoke is far from saturation point.
  - Field map is used in FLUKA simulations.

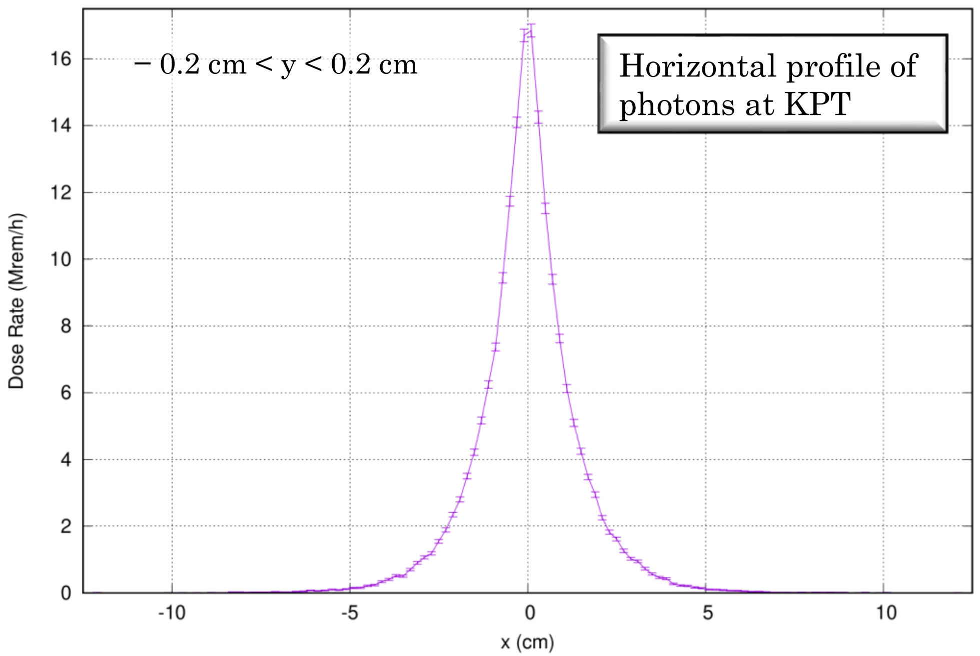


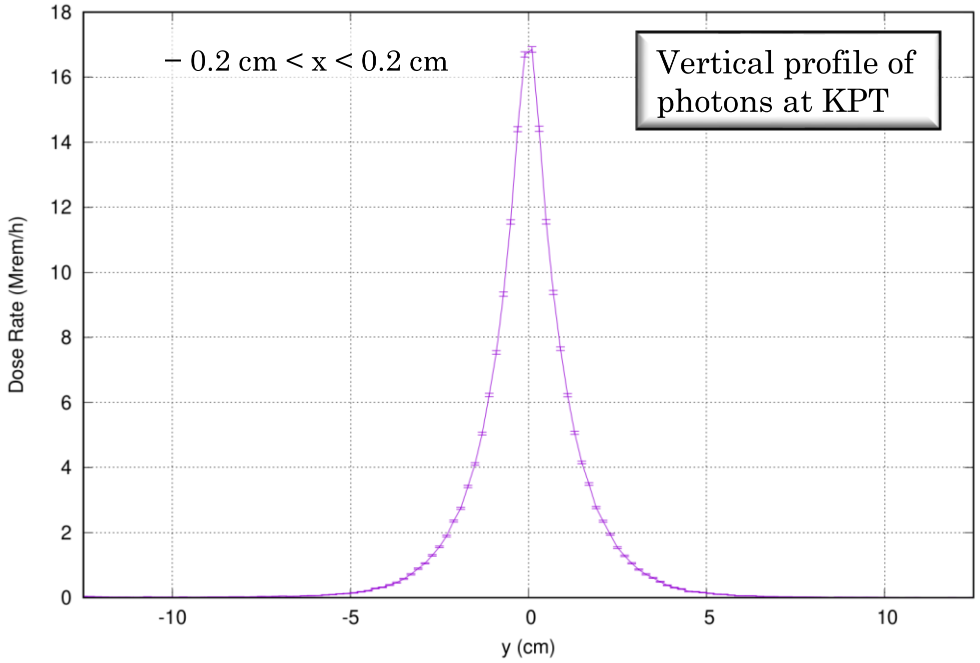


Photon Beam

- We used FLUKA to estimate the beam profile at KPT.
- Clean photon beam profile with $\sigma_{\gamma} \approx 1.5$ cm width.
  - The photon beam width at KPT is dominated by multiple scattering in the 10% radiator.
  - Vertical distribution has a slight asymmetry (on 0.1% level) favoring negative y-s.
- Charged particle and neutron rates from CPS measured at the KPT location is expected to be very small compared to the photon flux.







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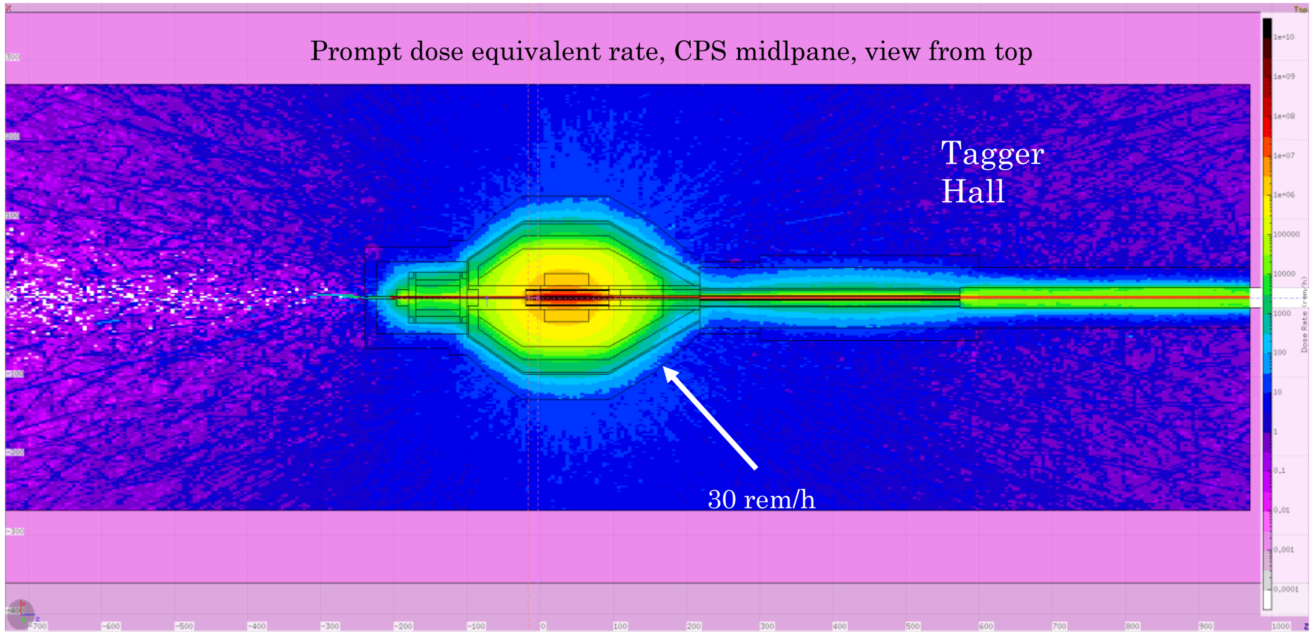
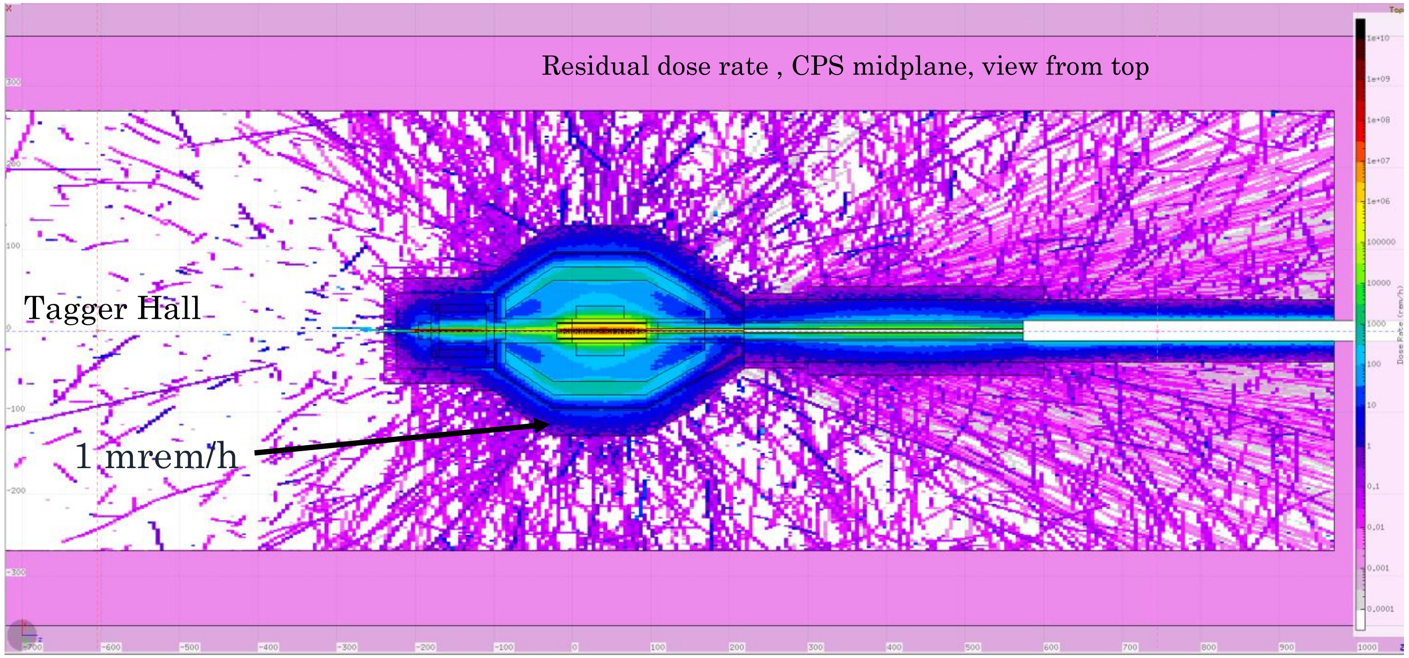
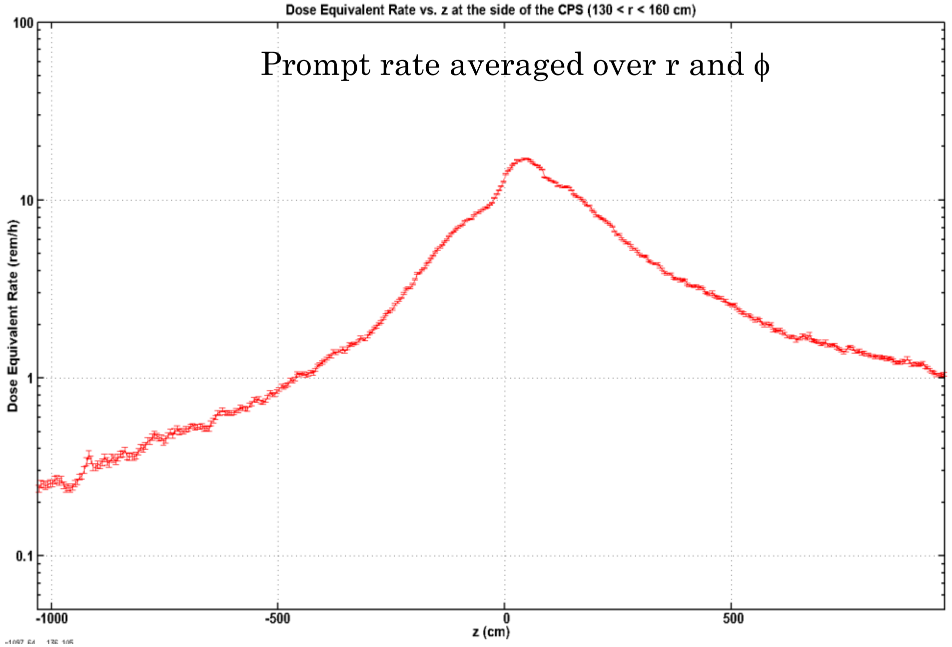
Dose Rates

- Prompt dose rate inside Tagger Hall around CPS is ~20 rem/h.
  - ~30 rem/h right at the CPS surface.
  - <10 rem/h far away from CPS
- We evaluated residual dose rate after 10000 hours of continuous operations and 1 hour cool-off time.
  - The rates outside of CPS are expected to be <1 mrem/h, that is well within JLAB limits.







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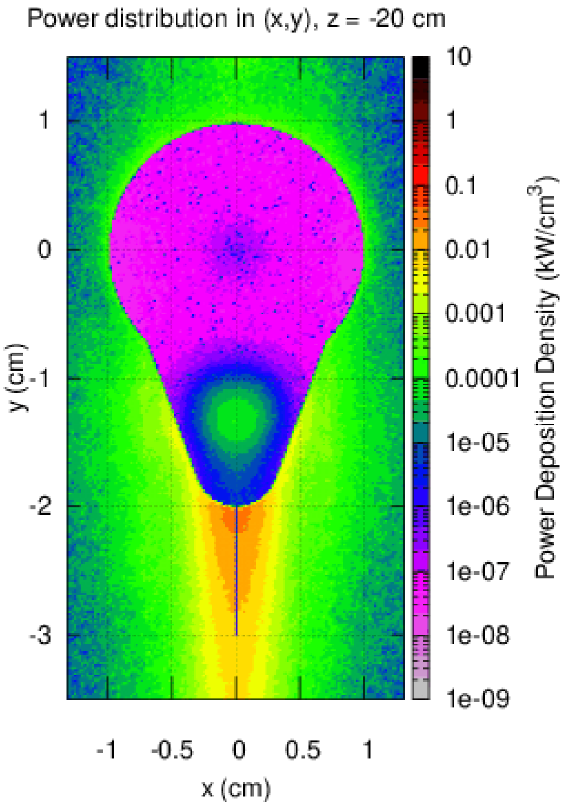
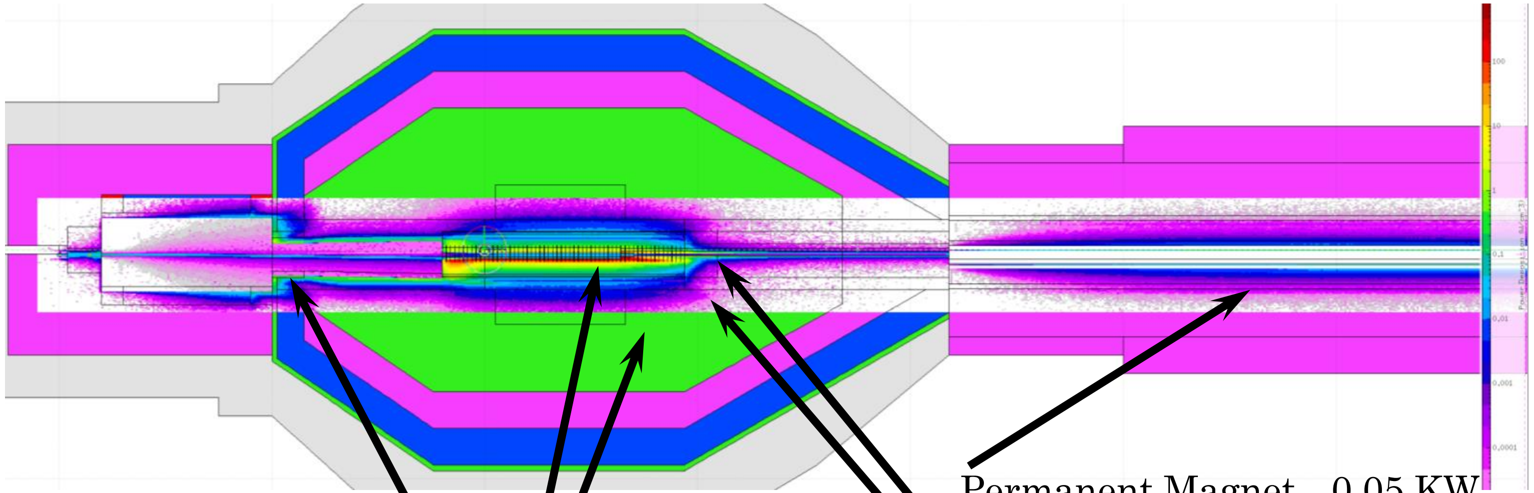
Power Deposition in the Absorber

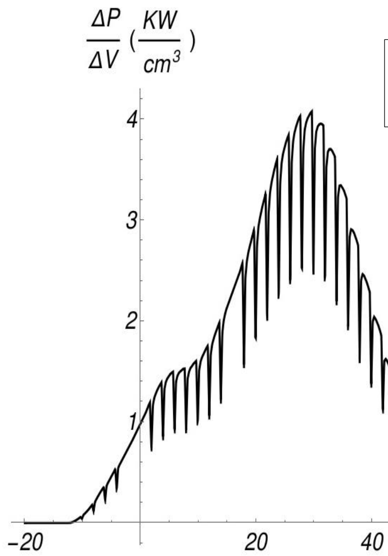
- FLUKA provides an output file with power deposition densities in 3D.
  - 37M data points inside absorber
- Almost all of the remaining electron beam power (> 98%) is deposited into the copper absorber.
  - Most likely that only absorber needs cooling.
  - Must prevent heat transfer from absorber to surrounding volumes.



Color indicates power deposition density (KW/cm^3)



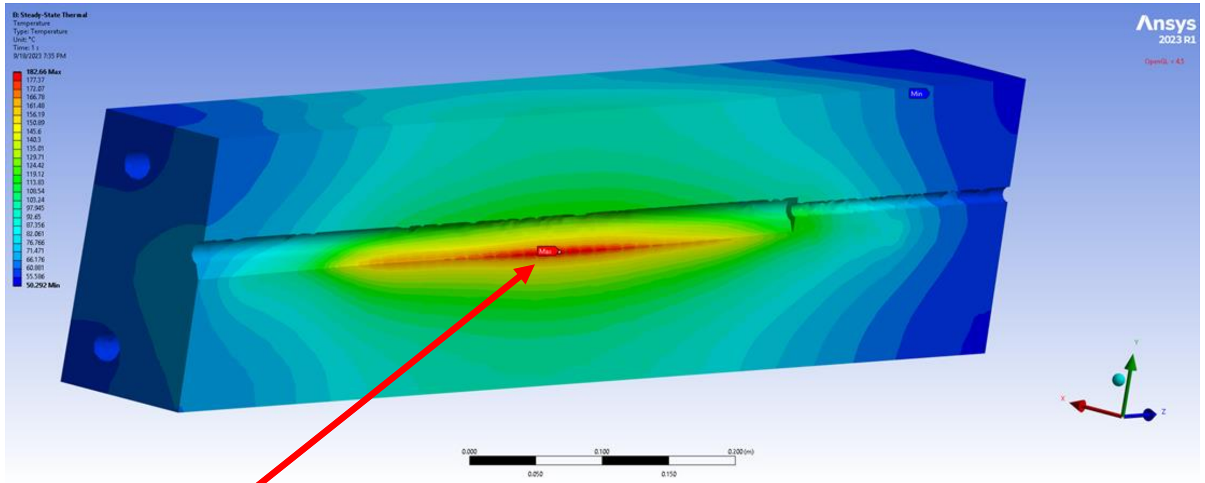
CPS Entry collar	0.03 KW
Copper Absorber	53.5 KW
Lead around Abs.	0.08 KW
Permanent Magnet	0.05 KW
CPS Exit Collar	0.10 KW
Steel base at Abs.	0.30 KW



Power deposition density near (x,y)=(0,0) line

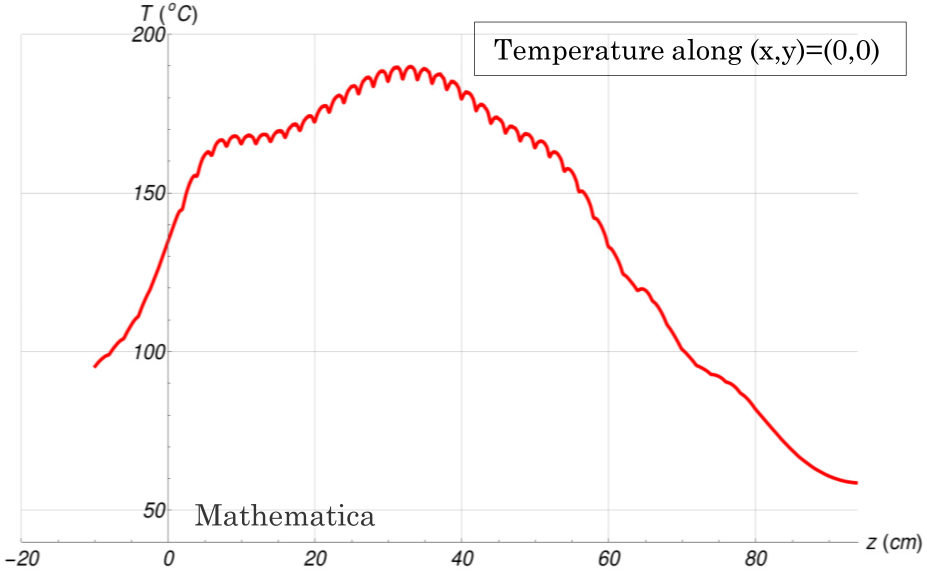
Temperature

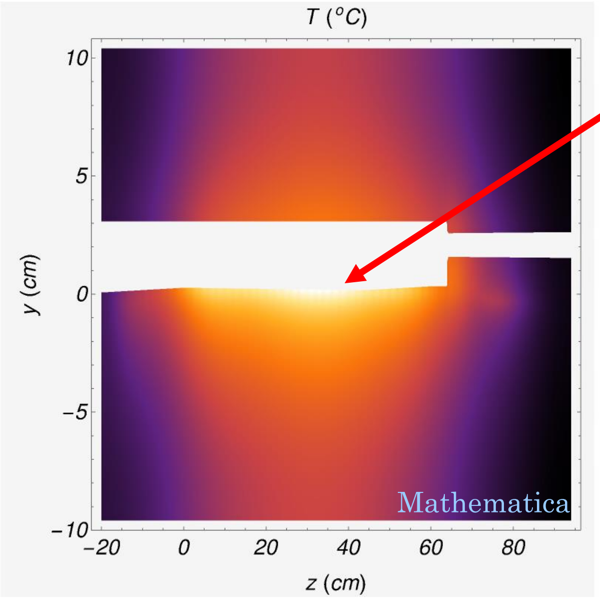
- Temperature calculations in the "isolated" absorber is done using power deposition maps obtained using FLUKA.
- Two independent calculations are done by two people using two different software packages:
  - ANSYS software, popular among engineers
  - Wolfram Mathematica software, popular among scientists
  - The results differ by less than ~10 ^{O}C
- The temperature at the hotspot is expected to be
  - ~190 ^{O}C at nominal beam parameters, according to Mathematica.
  - ~183 ^{O}C at nominal beam parameters, according to ANSYS.
- There is no possibility for high temperatures at the outer boundaries of the absorber, except the front side.
  - Still need to perform ANSYS evaluation for the whole CPS.

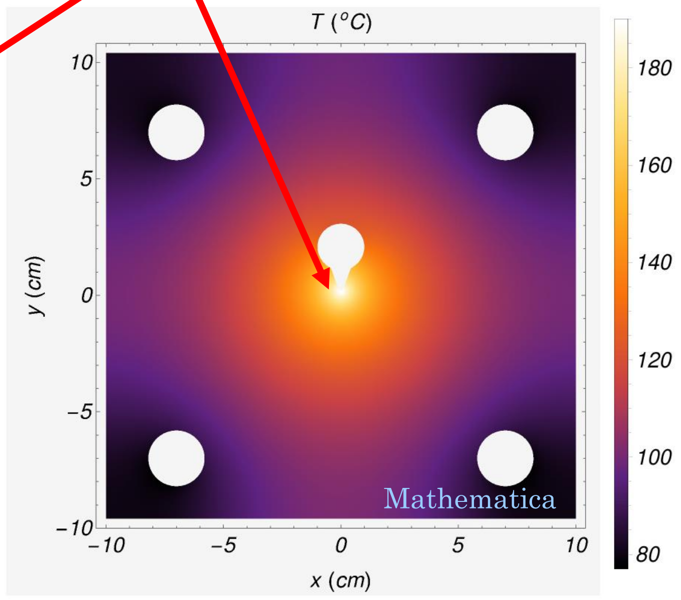


$T_{max} \approx 183\ ^{O}C$

$T_{max} \approx 190\ ^{O}C$







Electron Beam Requirements

- It is important to have a good beam tune on the radiator.
  - Excessive radiation in Tagger Hall.
  - Higher temperatures in the CPS absorber.
- We found that beam rastering will not be necessary.
  - We will need to make sure that beam profile is wide using wire scans at CPS.
- Install a girder just upstream of CPS with:
  - BCM to measure the beam current,
  - BPM to measure beam positions,
  - Wire scanner for beam widths.
- FSD trips on
  - Large electron beam positions excursions,
    - Use a collar and ion chambers.
  - Electron beam angle excursion,
    - Measure photon beam position at KPT.
  - Magnet current deviations.
    - Use power supply ADCs.
    - Field sensors or pickup coils inside the magnet
- Keep Hall D radiator scanner with ~10^4 dynamic range for the halo measurement.

Test Configuration Name (klcps69)	Z_{max} (cm)	T_{max} (^oC)	T_{cold} (^oC)
All Nominal	37	230	100
$\sigma^{(x,y)}_{beam}$ = 0.33 mm	43	290	105
$\sigma^{(x,y)}_{beam}$ = 1.5 mm	8.5	245	100
97% B-field	56.5	245	100
103% B-field	33	240	100
-1mm shift in Y	8	265	110
+1mm shift in Y	57	265	105
-0.5mrad angle in Y	8.5	265	110
+0.5mrad angle in Y	58	275	105
+1mm shift in X	8.2	260	100
+0.5mrad angle in X	8	260	100

Parameter	@ CPS Radiator	@ KPT
Beam Current	$50\ nA \le I_B \le 5\ \mu A$	N/A
Beam Size	$0.5\ mm \le \sigma \le 1.5\ mm$	$\sigma \le 1$ cm
Beam stability (@ 1 Hz)	$\sigma \le 0.2$ mm	$\sigma \le 2$ mm
FSD is tripped at	$\|\Delta x\| > 1$ mm or $\|\Delta y\| > 1$ mm	$\|\Delta x\| > 1$ cm or $\|\Delta y\| > 1$ cm
Beam halo (halo-to-peak)	$< 10^{-4}$ at $r > 5\sigma$	N/A

Summary

- We are in the advanced stages of developing a conceptual design of CPS for Hall D.
  - It should provide photon beam at KPT that would meet KLF requirements.
  - We will use a movable platform to be able to restore GlueX beamline.
  - The conceptual design is still in progress.

- We performed FLUKA simulations to estimate the radiation levels around CPS.
  - Radiation environment should be similar to what GlueX would have at 5μA.

- We are working on optimization of the basic design.
  - Optimize the absorber and magnetic field to further lower the temperature.
  - Minimize thermal stresses and deformations.
  - Avoid using Barite Concrete in shielding as its delivery may pose schedule risks.
  - Design CPS such that we can isolate a 10-ton core that can be transported as a single item.

- Engineering design will be the next step.
  - Hall D will hire and/or borrow an engineer.

- At some point the engineering designed will need to be endorsed by KLF collaboration.
  - A formal procedure needs to be defined.

Thank You!

CPS Requirements

- Intense photon flux of $\Phi_\gamma > 10^{12}$ photons per second with $1.5\ \mathrm{GeV} < E_\gamma < 12\ \mathrm{GeV}$.
- Photon beam spot size at KPT with $2 \cdot \mathrm{FWHM} < 6\mathrm{cm}$ to make full use of KPT size.
- Radiation environment in the Tagger Hall similar or better than what GlueX would get with 5μA electron beam on nominal GlueX diamond radiator.
  - Prompt equivalent dose rate of ~20 rem/h.
  - Activation does rate <5 mrem/h after 10000 hours of operations and 1 hour of cool-down time.
  - RadCon limits <1 mrem/h for prompt equivalent dose rate outside of the Tagger Hall.
- Cooling system design that is sufficient to handle ~54 kW power delivered to CPS.
  - It will need to be closed-circuit system to avoid activation/contamination.
- GlueX beamline should be restored relatively quickly without disassembly of CPS.
  - GlueX photon beamline is wider than CPS beam channel and is under vacuum.
  - We decided to build a movable platform to move CPS beam-left.
  - There is sufficient space in the tagger hall for the current CPS design.

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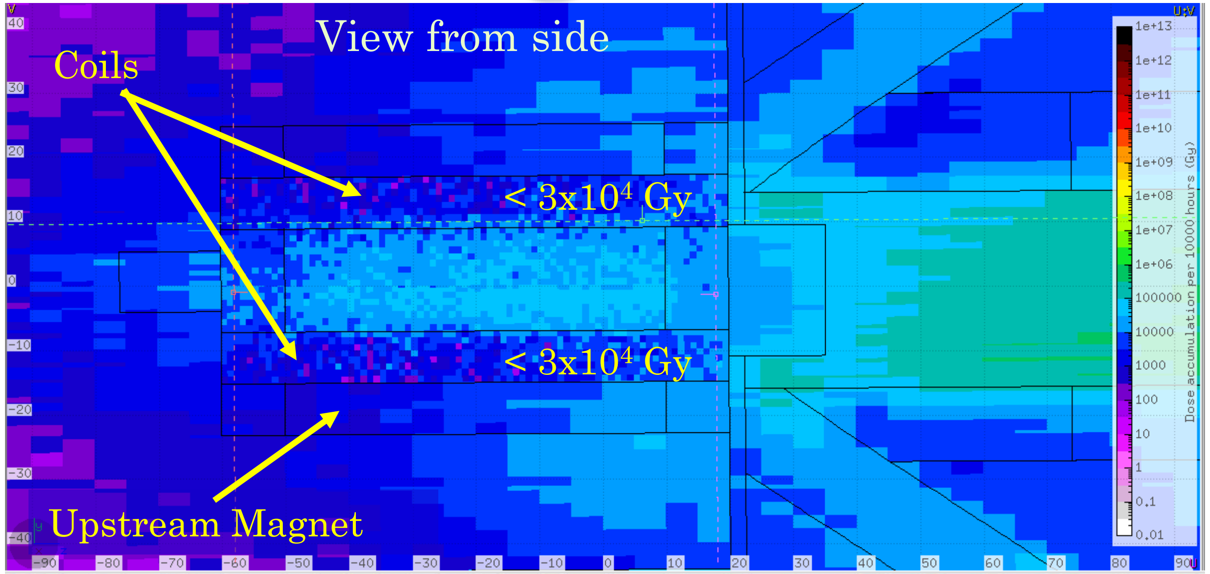
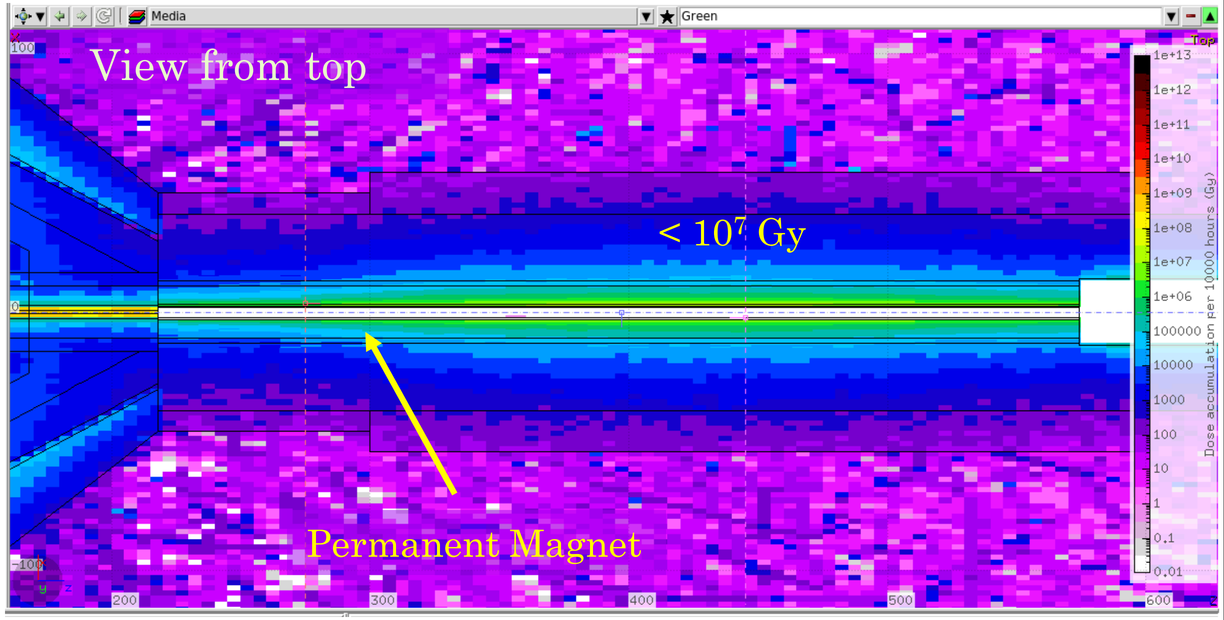
Accumulated Doses in the Magnets

- Accumulated dose to upstream CPS magnet coils in 10000 hours is expected to be $3x10^4$ Gy.
  - Magnet coil insulation made of cyanate ester resins can handle over 10^6 Gy dose.
    - Reference: P.E. Fabian, et al "Novel Radiation-Resistant Insulation Systems for Fusion Magnets," Fusion Engineering and Design, Vol. 61-62, pp. 795-799, 2002

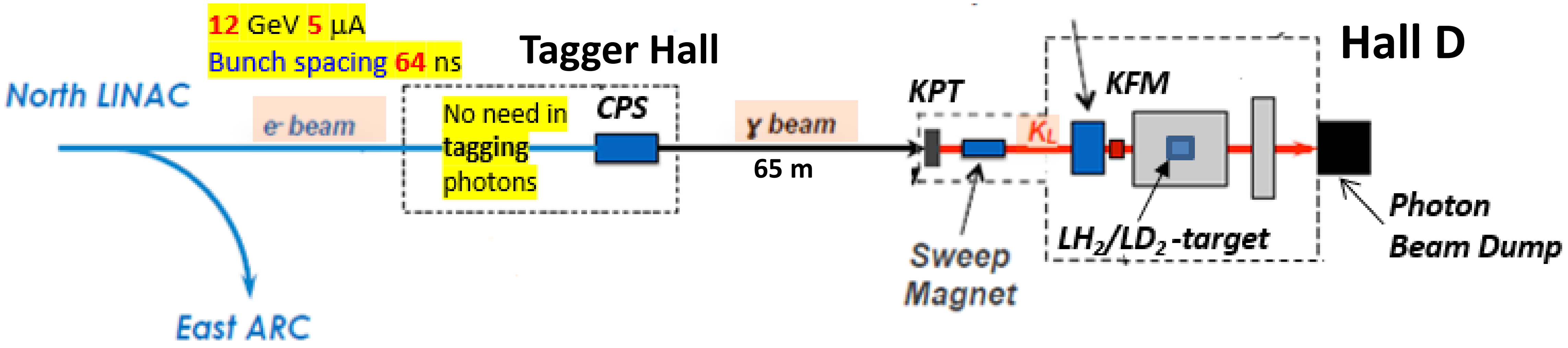


- Accumulated dose in the permanent magnet in 10000 hours is expected to be on the level ~10^7 Gy.
  - Hall D strontium ferrite permanent do not change at such a dose.
    - FNAL did not observe any change in B-field after a dose of10^7 Gy.
    - FNAL gave an upper limit of 1% change, as specified in the magnet specs.



KLF Layout

- KLF experiment needs to produce high intensity photon beam upstream of KPT.
- CPS stands for Compact Photon Source; it has been proposed as the photon source.
- The only possible location for such a source is the Tagger Hall.
- CPS beamline will require major modifications to GlueX photon beamline.



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Accumulated Dose in 10000 hours

- Accumulated doses are evaluated outside of CPS.
  - We will use this map for equipment installations in the tagger hall.
- CPS is not expected to be disassembled for a very long time.
  - It can be moved aside to restore GlueX photon beamline.