Conceptual Design of CPS for KLF

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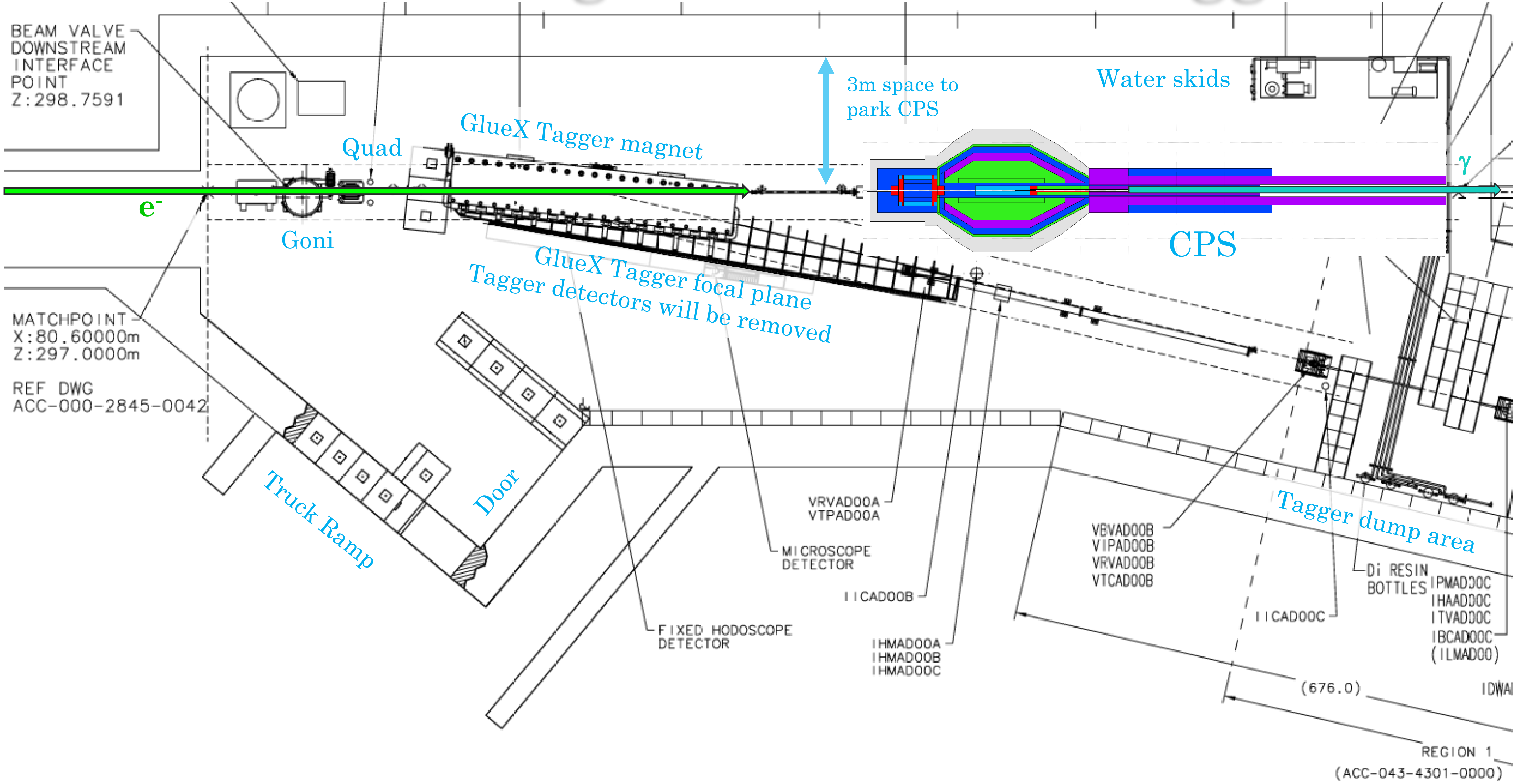
Overview

- 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 90 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 ~$1M for CPS
  - Upstream beamline instrumentation will be extra.
- Tim will discuss engineering aspects in detail.

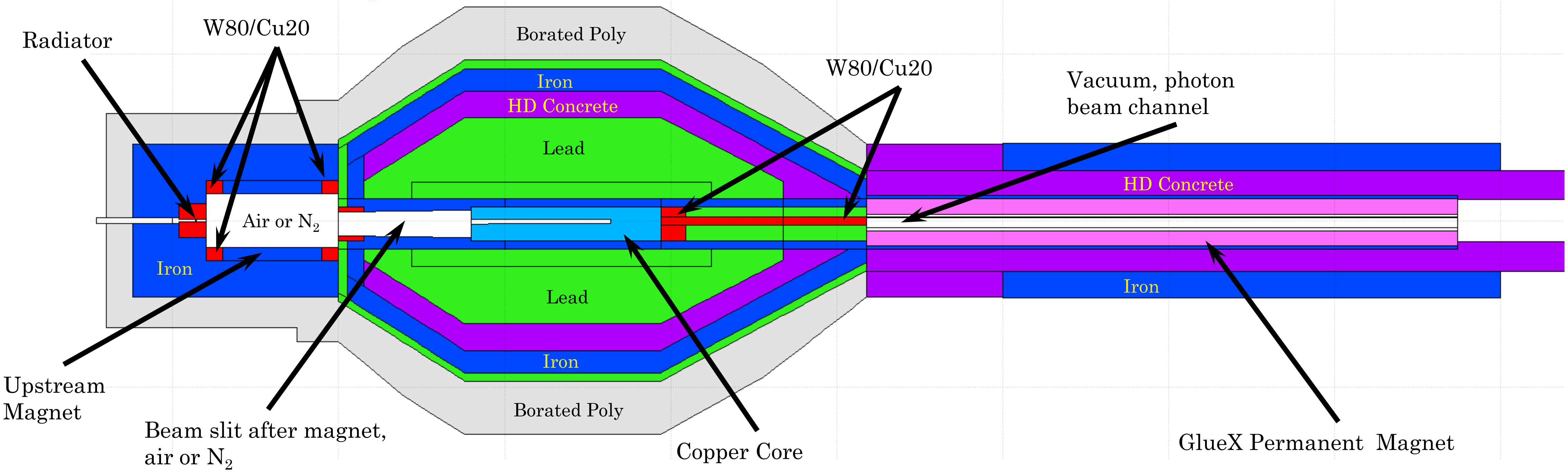
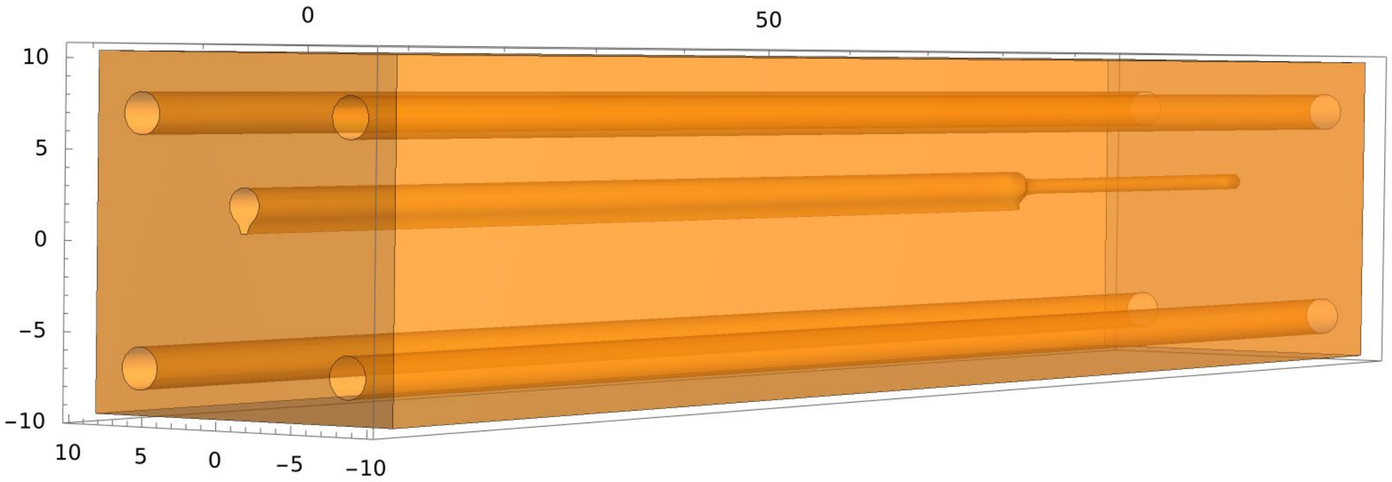


Table of Weights

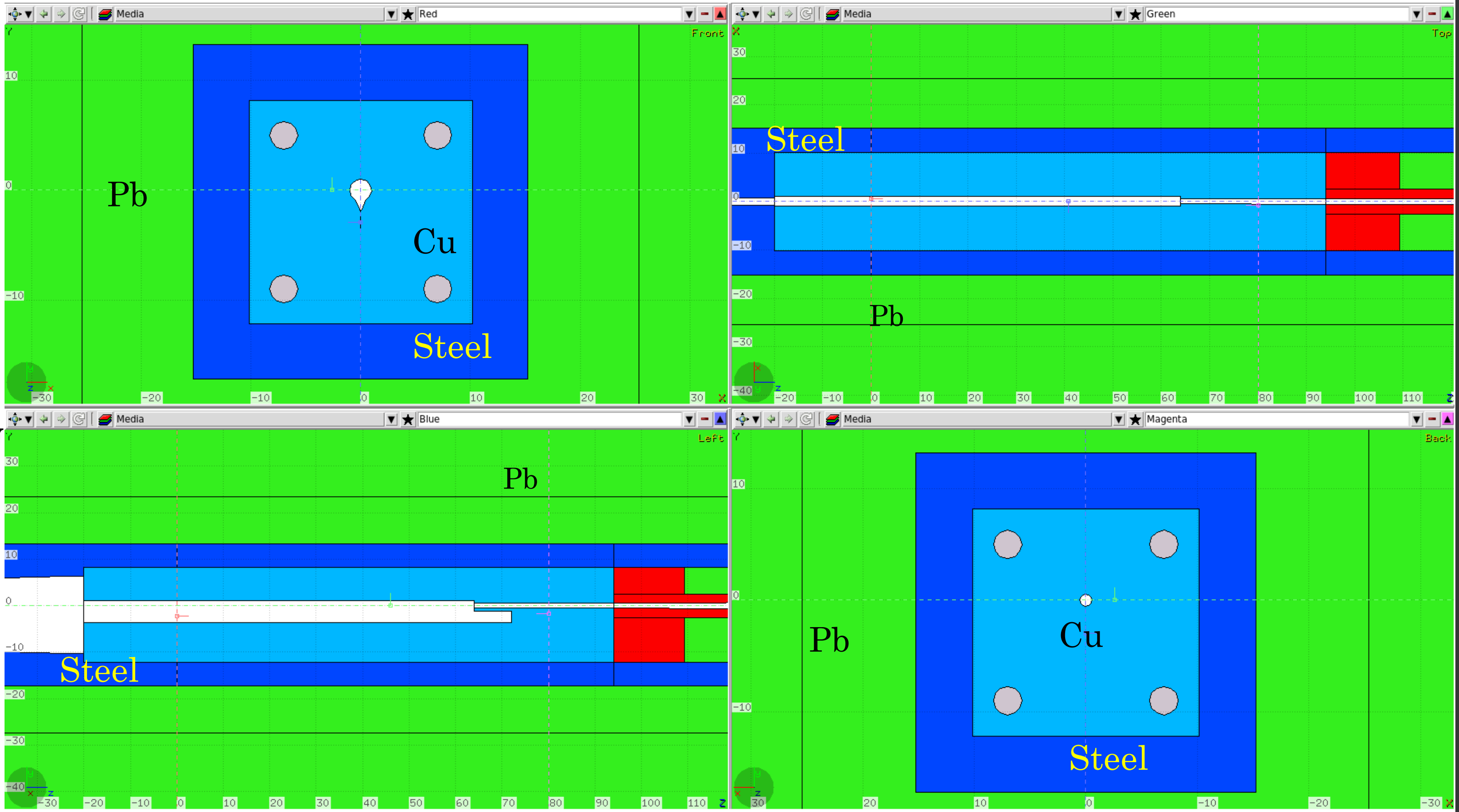
(metric tons)

Material	Magnet	CPS_incl_Pb-Skin		ExitLine	Total
Yoke	1.0	0	0	0	1.0
Cu	1.1	0.4	0	0	1.5
WCu	0.47	0.25	0	0	0.72
Steel	0	1.29	0	0	1.29
W powder	0	0.0	0	0	0.0
Pb	0	23.31	8.91	0	32.22
HD concrete	0	7.61	0	11.81	19.42
Iron	4.53	14.73	0	9.06	28.32
B.Poly	1.0	5.57	0	0	6.57
total	8.1	62.1		20.9	91.1

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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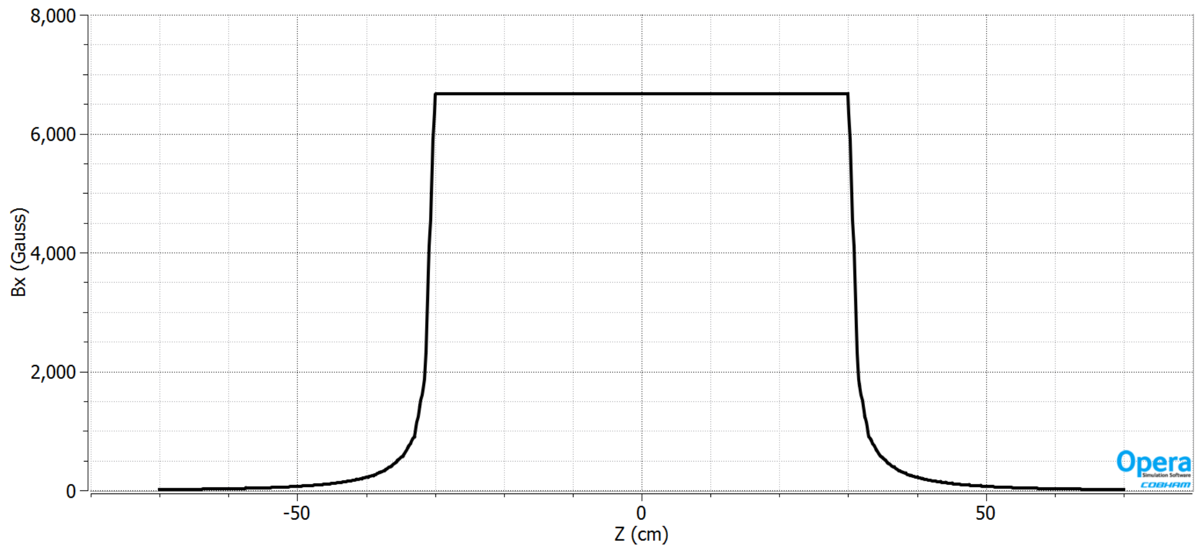
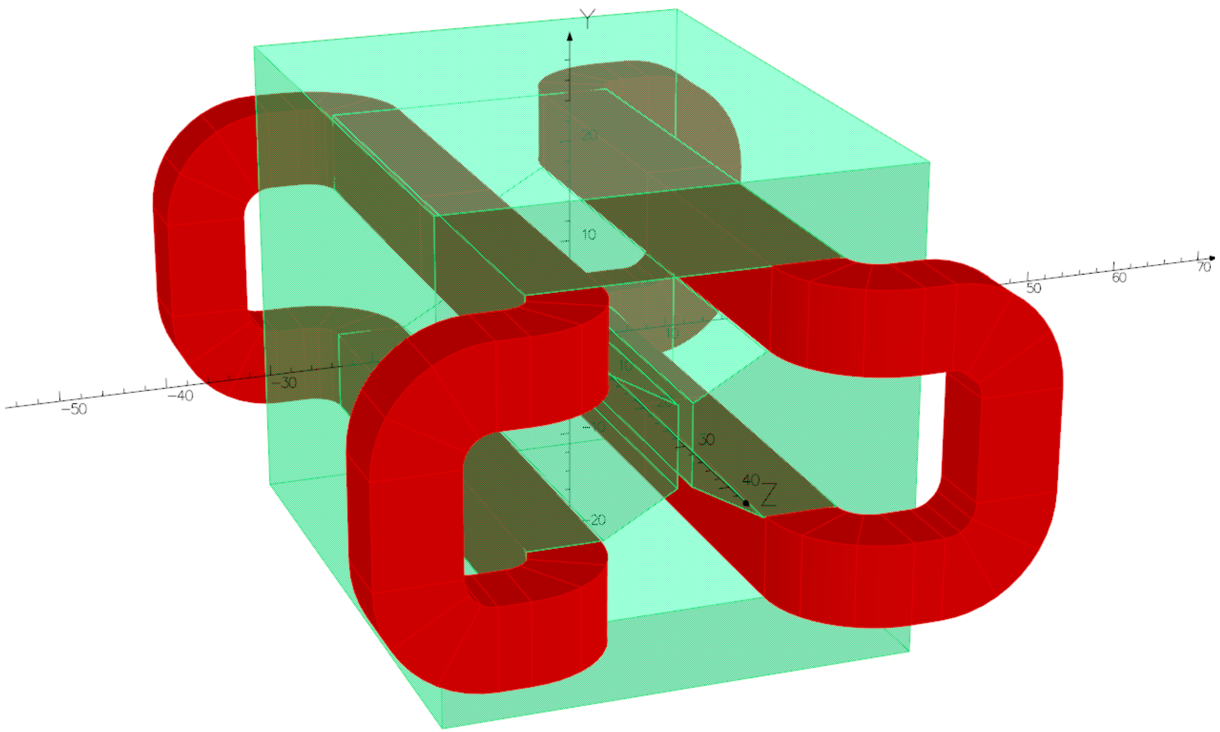
Upstream Magnet

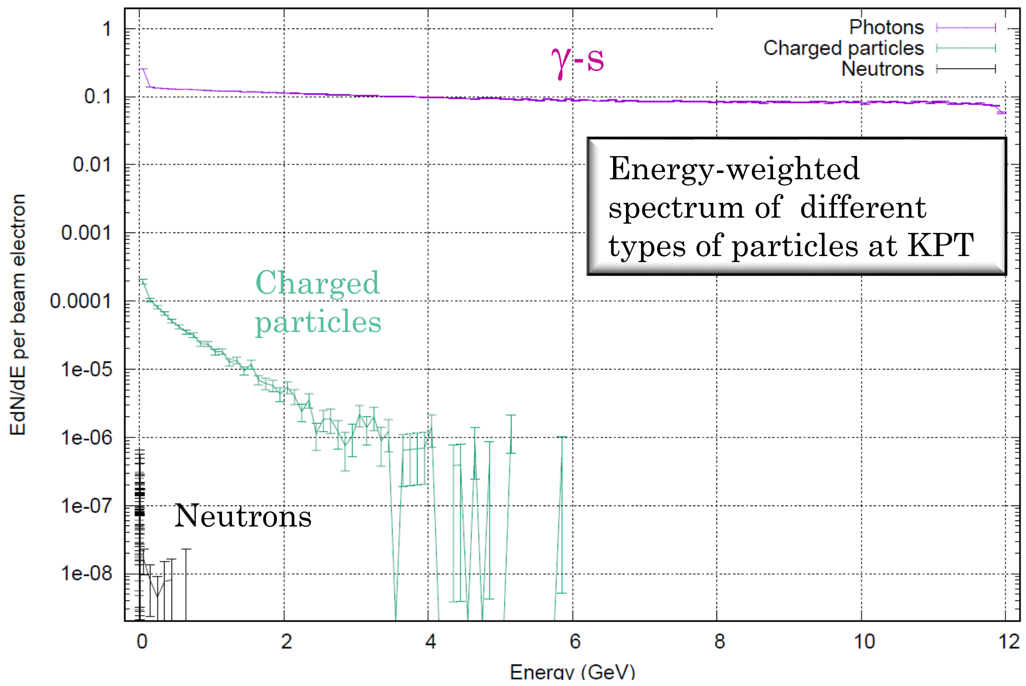
- Current CPS design requires ~0.4 T·m magnetic field in the x-direction.
- We developed a draft model of the magnet.
  - Magnet has 60 cm long coils.
  - Bedstead shape of coils for less radiation exposure.
  - The closest distance from coils to the beam center is ~11cm.
- The gap should be on the order 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.

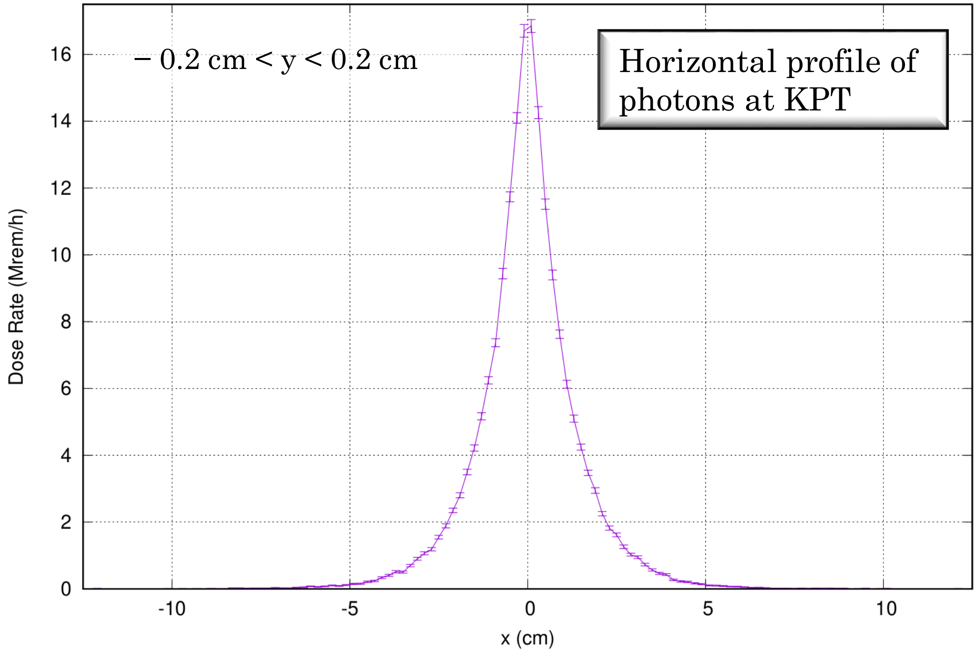


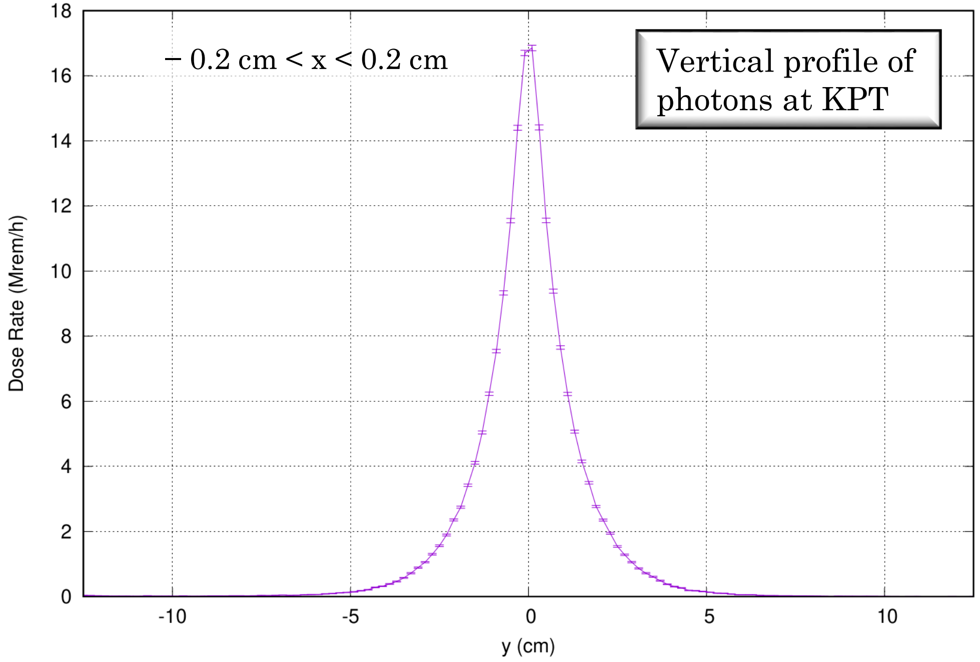


Photon Beam

- 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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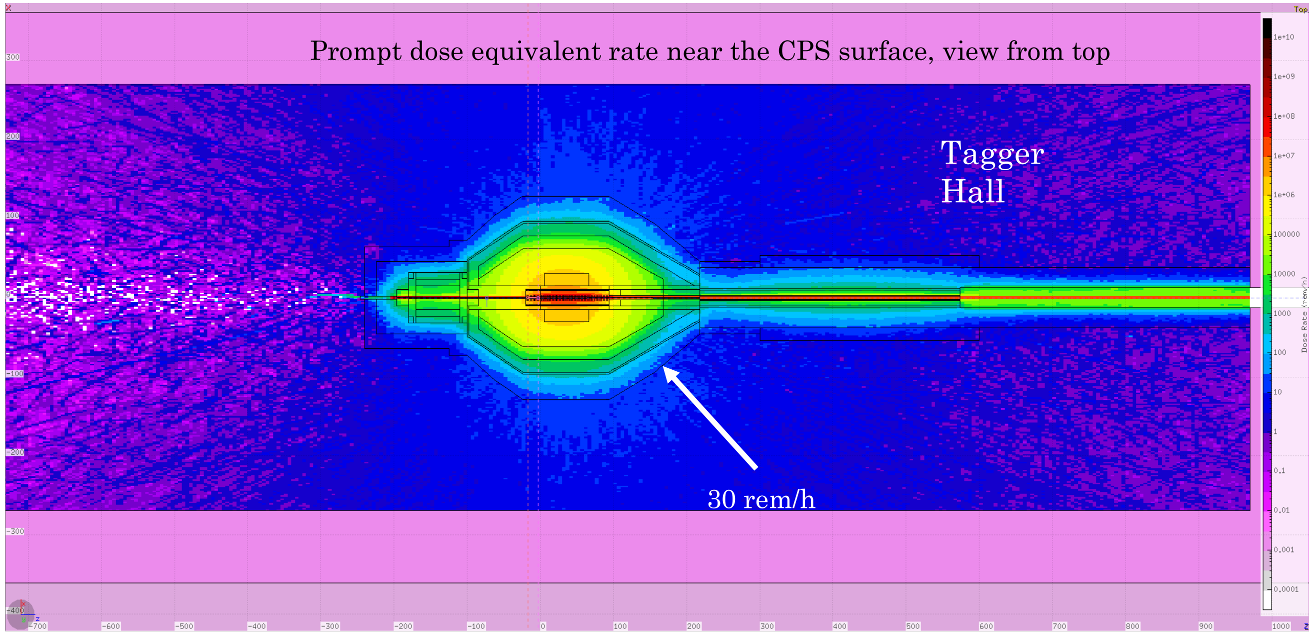
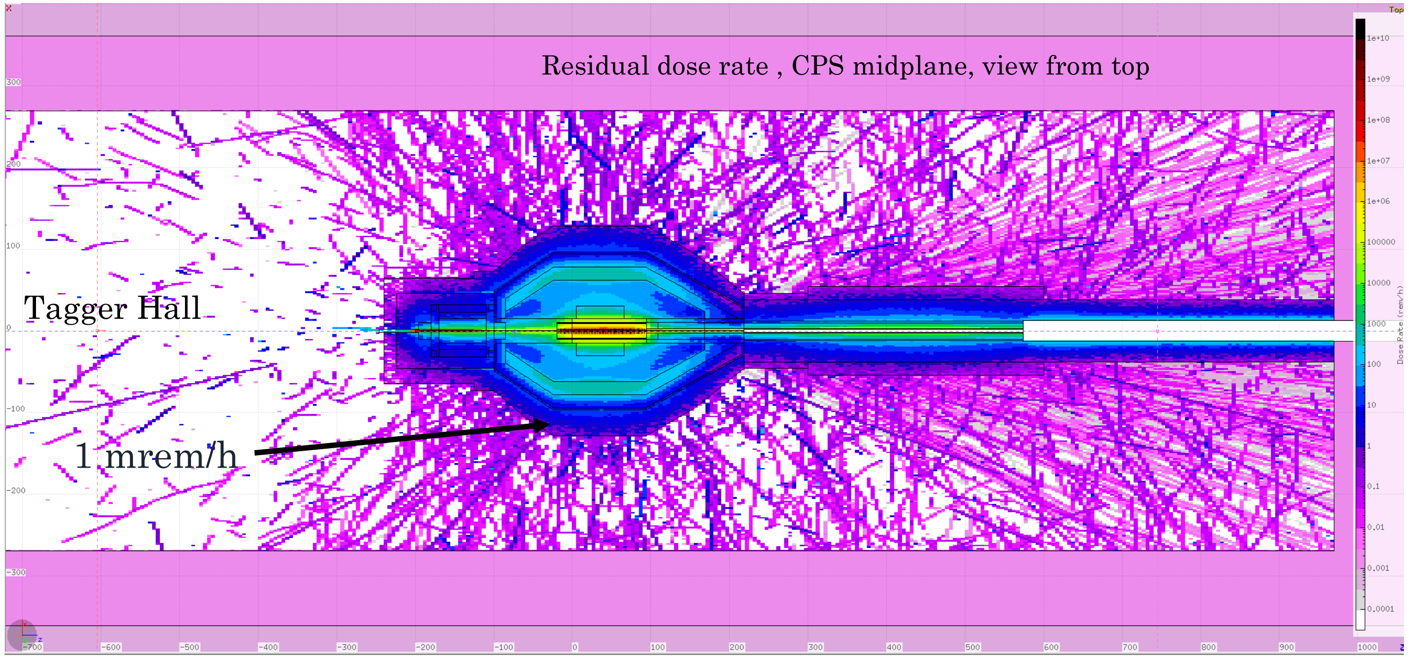
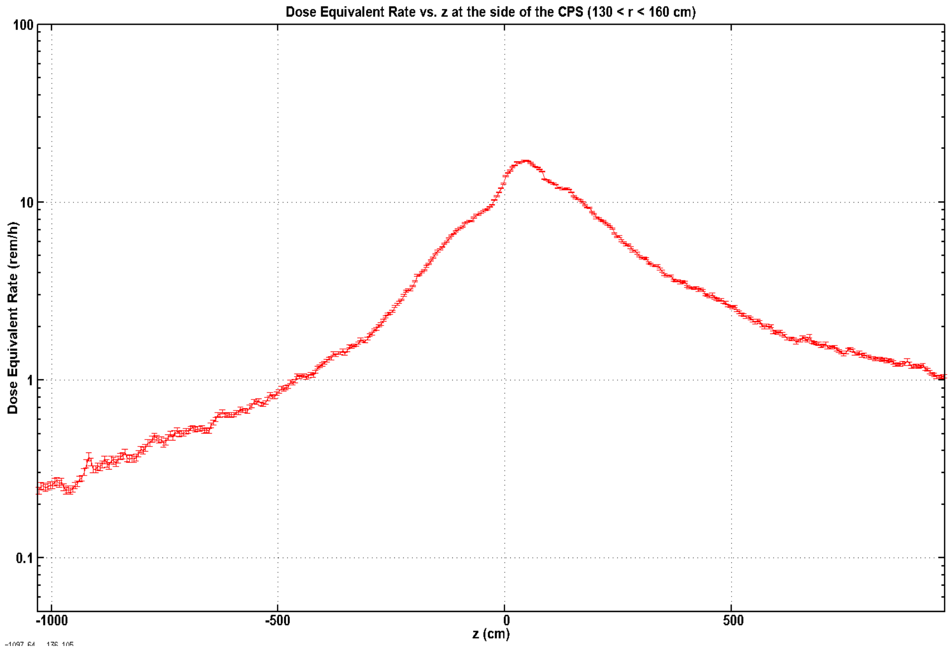
Dose Rates

- 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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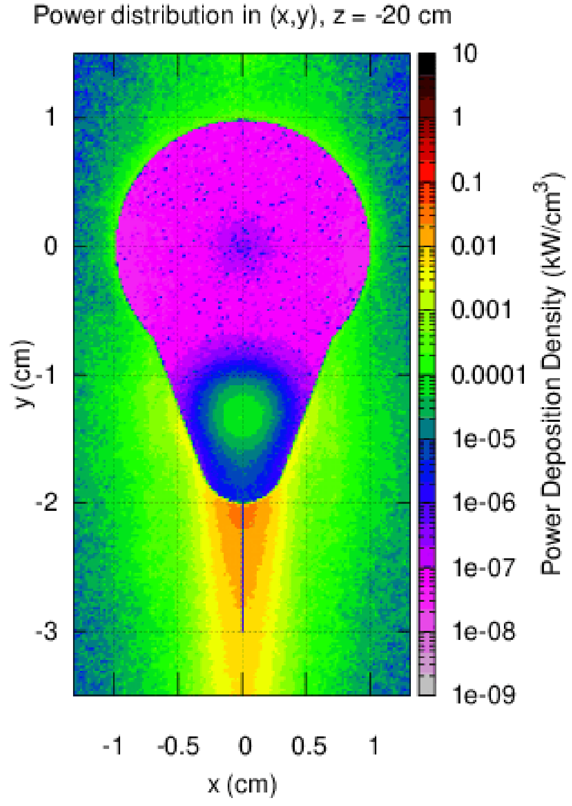
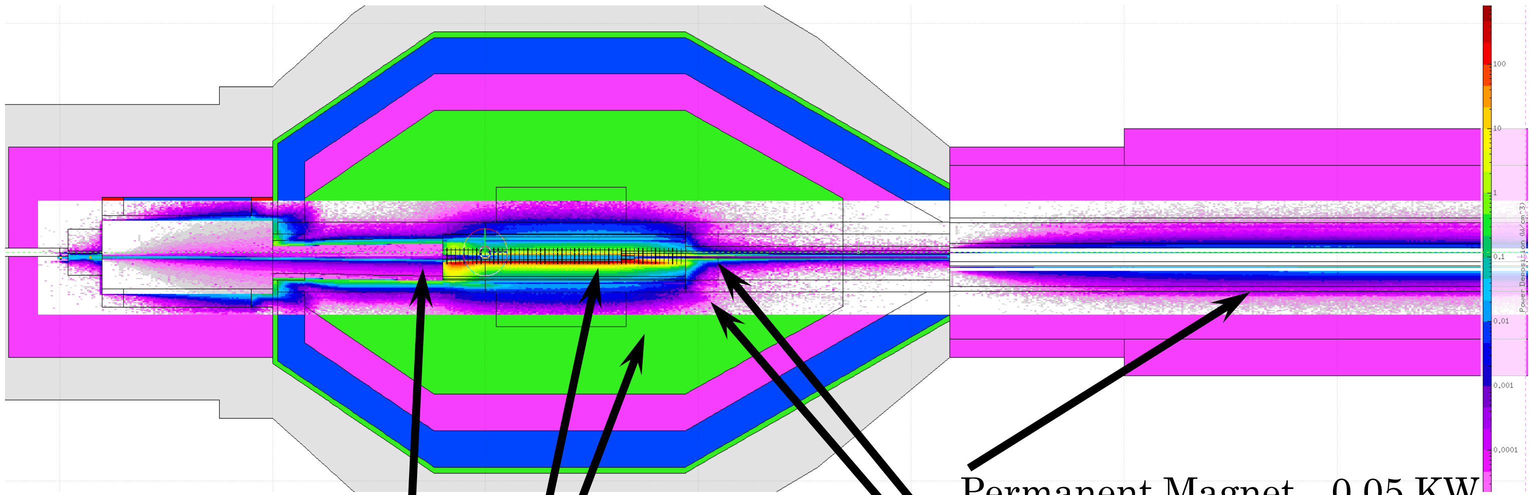
Power Deposition in the Absorber

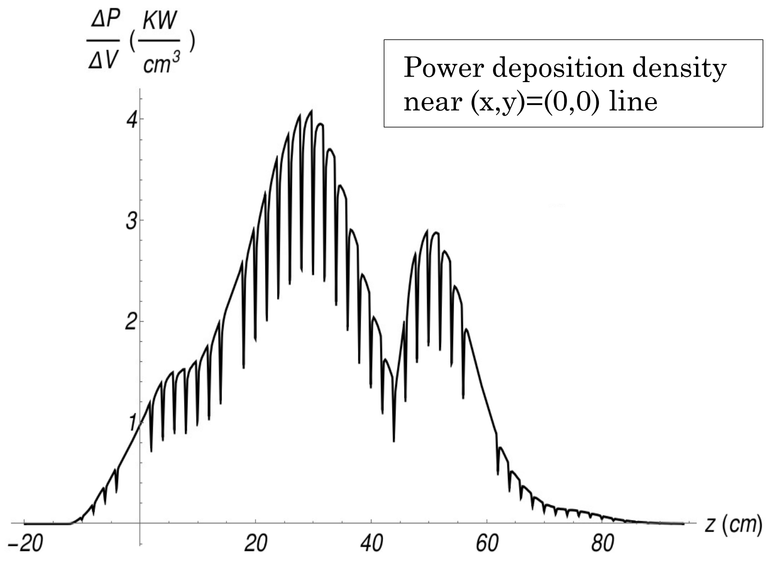
- FLUKA provides an output file with power deposition densities in 3D.
  - 37M data points inside absorber
- Almost all of the remaining electron beam power (> 98%) is deposited into the copper absorber.
  - Most likely that only absorber needs cooling.
  - Must prevent heat transfer from absorber to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



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

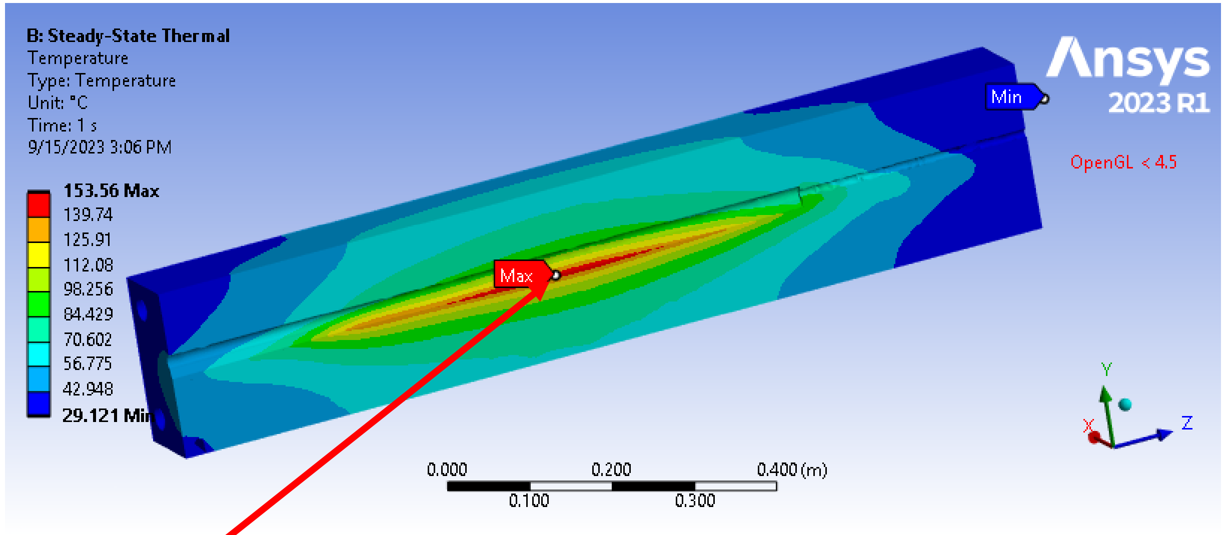


CPS Entry collar	0.03 KW
Copper Absorber	53.5 KW
Lead around Abs.	0.08 KW
Permanent Magnet	0.05 KW
CPS Exit Collar	0.10 KW
Steel base at Abs.	0.30 KW



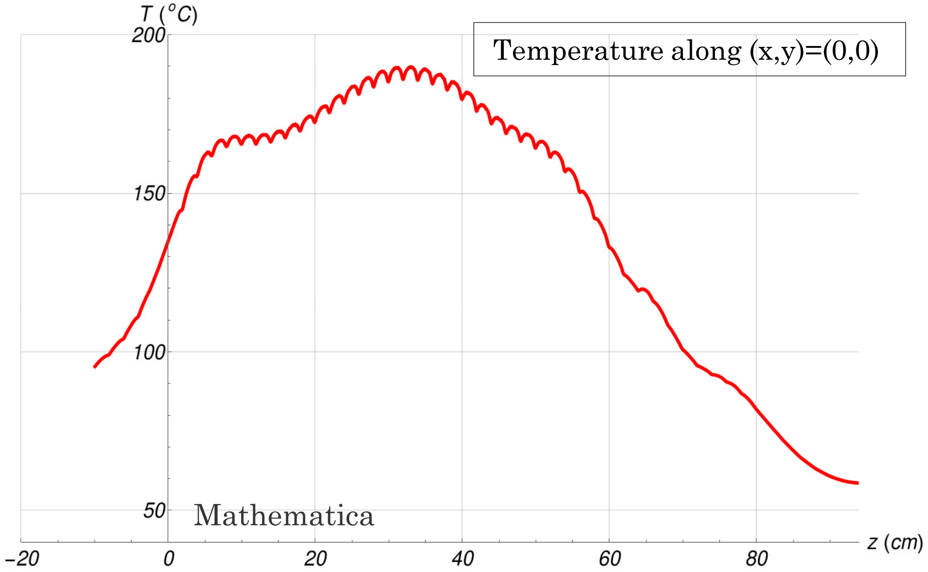
Temperature

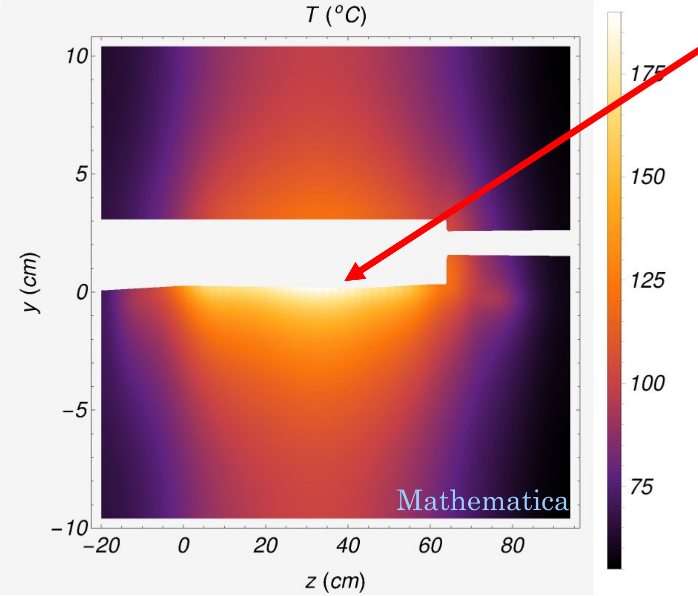
- Temperature calculations in the "isolated" absorber is done using power deposition maps obtained using FLUKA.
- Two independent calculations are done by two people using two different software packages:
  - ANSYS software, popular among engineers
  - Wolfram Mathematica software, popular among scientists
  - The results differ by about ~40 ^{O}C
- The temperature at the hotspot is expected to be
  - ~190 ^{O}C at nominal beam parameters, according to Mathematica.
  - ~153 ^{O}C at nominal beam parameters, according to Mathematica.
- 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.

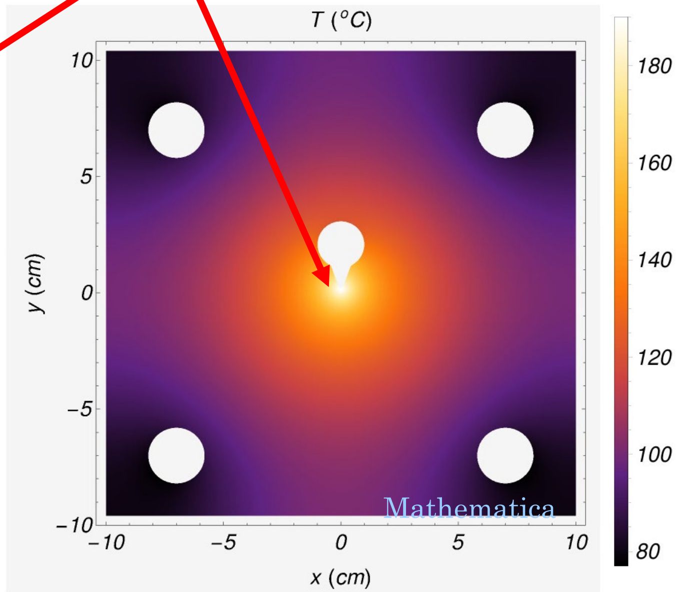


$T_{max} \approx 153$ ^{O}C

$T_{max} \approx 190$ ^{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 $\leq I_B \leq$ 5 μA	N/A
Beam Size	0.5 mm $\leq \sigma \leq$ 1.5 mm	$\sigma \leq$ 1 cm
Beam stability (@ 1 Hz)	$\sigma \leq$ 0.2 mm	$\sigma \leq$ 2 mm
FSD is tripped at	$\lvert\Delta x\rvert$ > 1 mm or $\lvert\Delta y\rvert$ > 1 mm	$\lvert\Delta x\rvert$ > 1 cm or $\lvert\Delta y\rvert$ > 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.

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

- 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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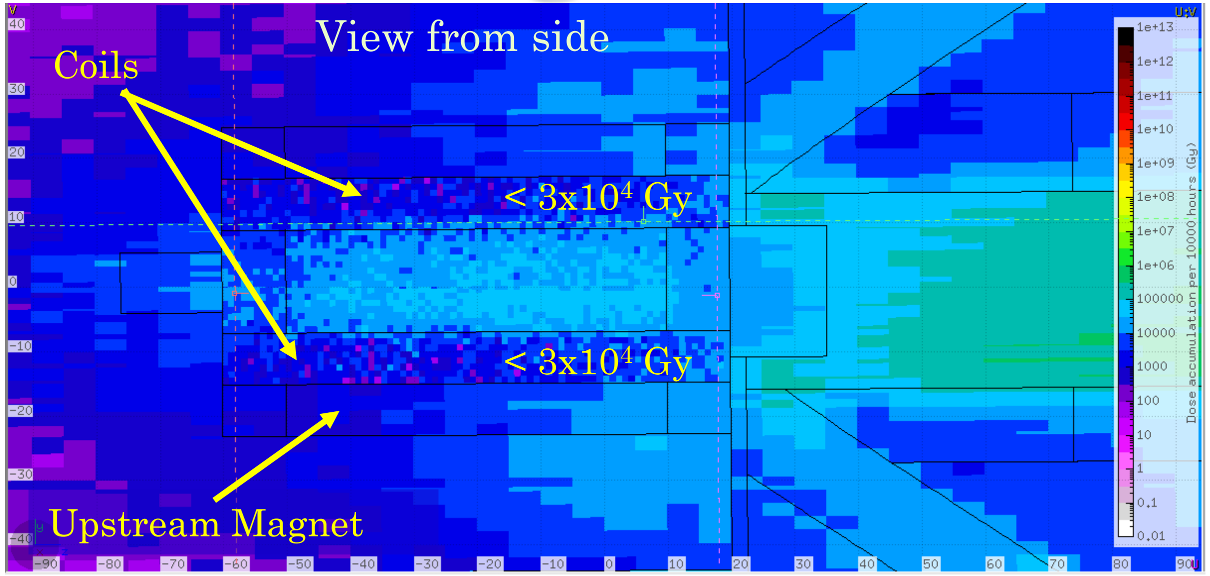
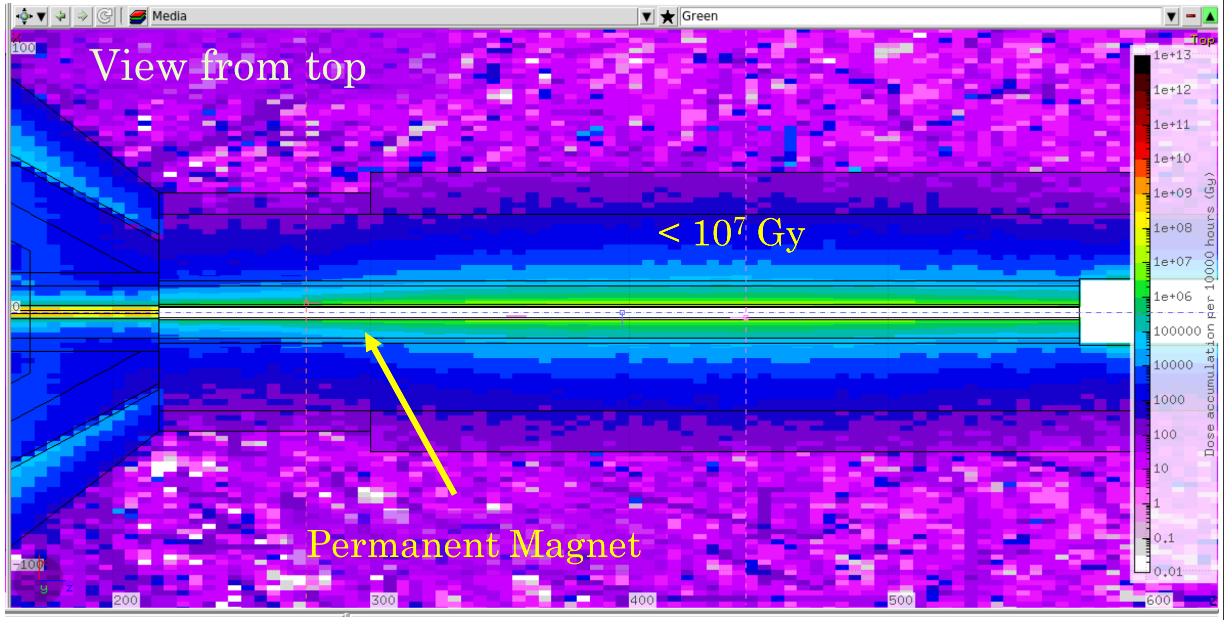
Accumulated Doses in the Magnets

- Accumulated dose to upstream CPS magnet coils in 10000 hours is expected to be $3\text{x}10^4$ 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

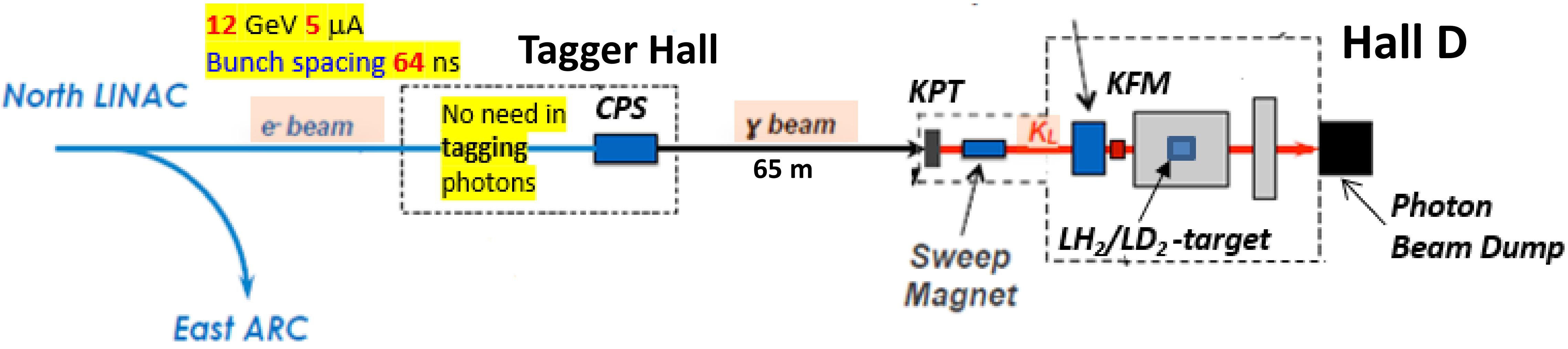


- Accumulated dose in the permanent magnet in 10000 hours is expected to be on the level ~10^7 Gy.
  - Hall D strontium ferrite permanent do not change at such a dose.
    - FNAL did not observe any change in B-field after a dose of10^7 Gy.
    - FNAL gave an upper limit of 1% change, as specified in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