I

Kaon Production Target (KPT) at Hall-D.

FLUKA model and calculations.

V. Baturin

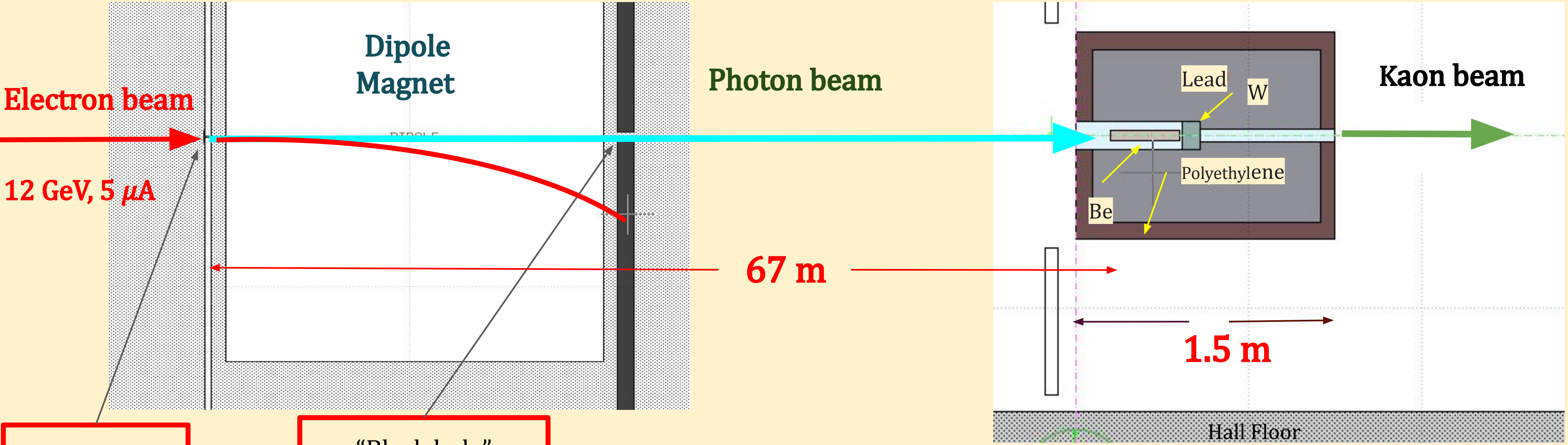
ODU

FLUKA model for γ-beam and KPT.

`[baturin@hallal1 KLMHALL]$ flair KLMPWRHALL.flair`

γ -beam formation

Kaon beam formation



Cu target
t = 0.143 cm,
d=4 cm.

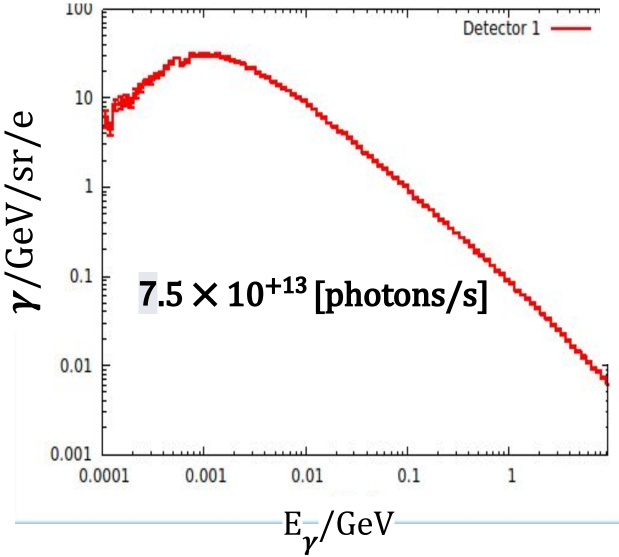
“Black hole”
collimator
d=6 cm
&
beam **dump**.

KPT specification

- **Beryllium cyl.** D×L = 6 × 40 cm × cm.
- **Lead cylinder** 100 × 132
- **Tungsten cylinder** 16 × 10
- **Borated Polyethylene** 120 × 150 ; Mass C/H/B= 56/14/30

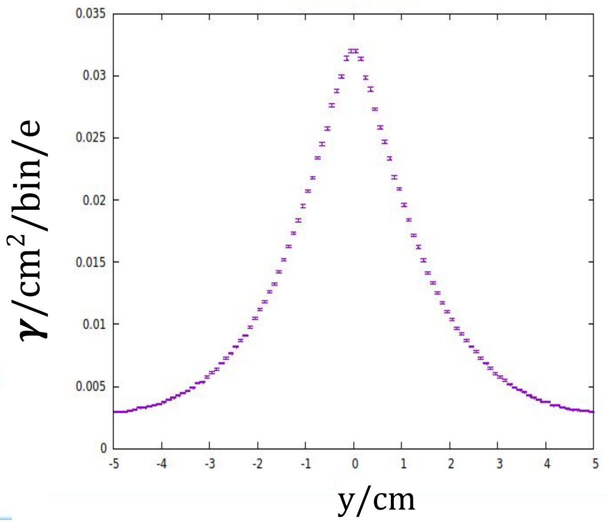
Photon and K-long beam energy spectra.

Energy Spectrum of $\boldsymbol{\gamma}$'s → Be

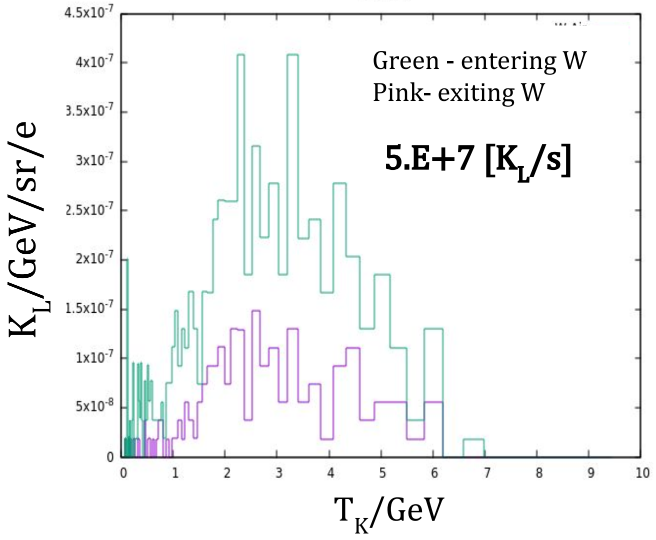


$7.5 \times 10^{+13}$ [photons/s]

Coordinate of $\boldsymbol{\gamma}$'s across Be



Energy Spectrum of K_L's.

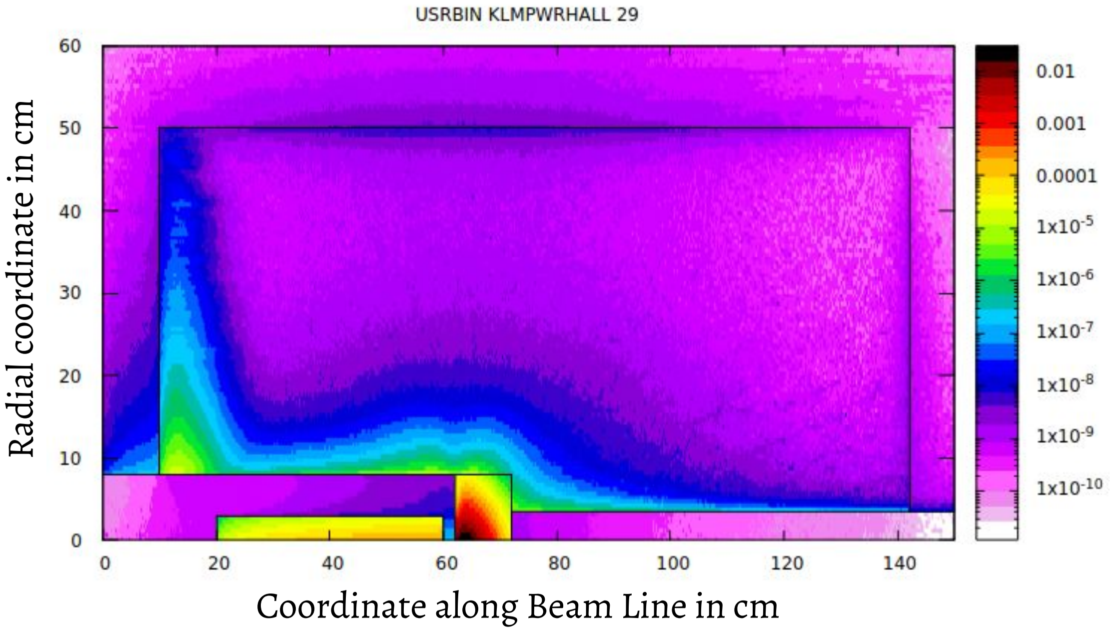


Green - entering W
Pink- exiting W

5.E+7 [K_L/s]

- The **integrated flux** on the Be cylinder **at 5 μA of primary e-beam** is **7.5 E+13 [photons/s]**
- Major part of the **photon beam hits the Be cylinder** (-3 cm < x < 3 cm).
- K_L yield ≅ 0.5 E-7 [K_L/GeV/sr/e]* 6.28 [sr] * 6 [GeV] =~2.E-6 [K_L/e] ; at 5 μA * 3.E+13 [e/s] ≅ **5.E+7 [K_L/s].**

Energy Deposition and Temperature in Kaon Production Target .



Energy deposition
in
GeV/cm³/electron

- To get **Power Density** in [GeV/cm^3/s] - **scale by the electron beam intensity** in [electrons/s].
- To get in **Watts/cm^3** - additionally **scale by 1.6022E-10 [J/GeV]**.
- Temperature **Calculations are done** by Tim Whitlatch.

II

Hall-C Compact Photon Source$^{(1)}$ (CPS) adoption for the KPT at Hall-D.

Hall-C e-beam parameters : 11 GeV , 2.7 μA, 30 kW.

Hall-D e-beam parameters : 12 GeV , 5 μA, 60 kW.

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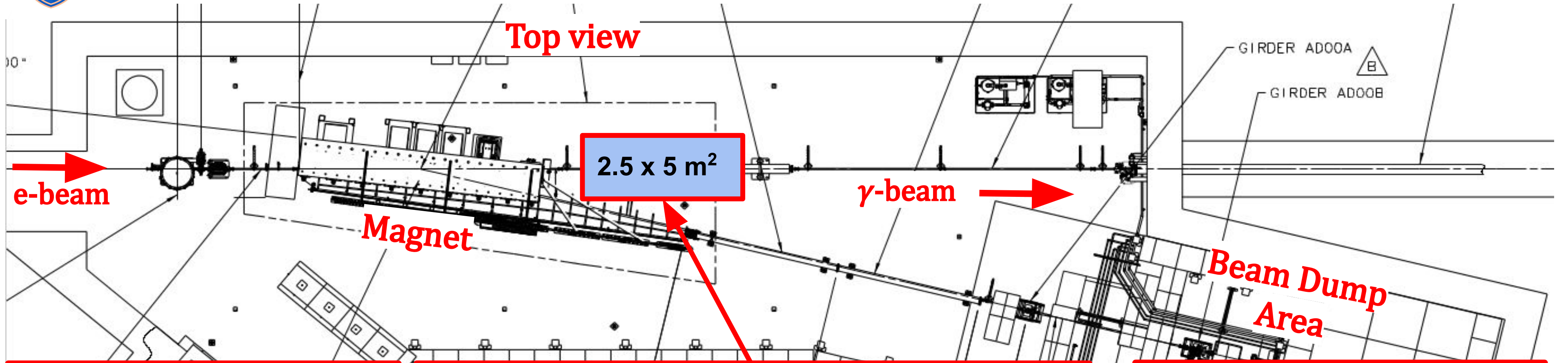
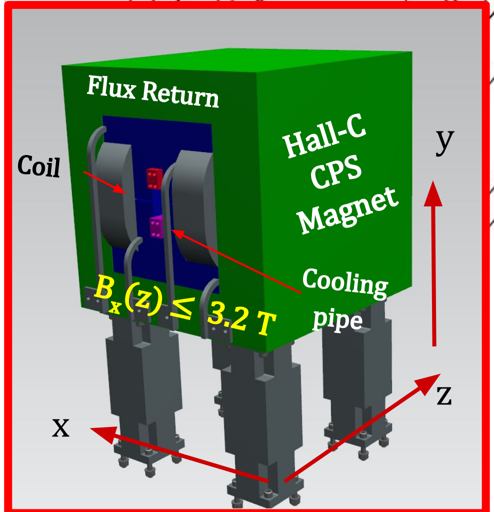
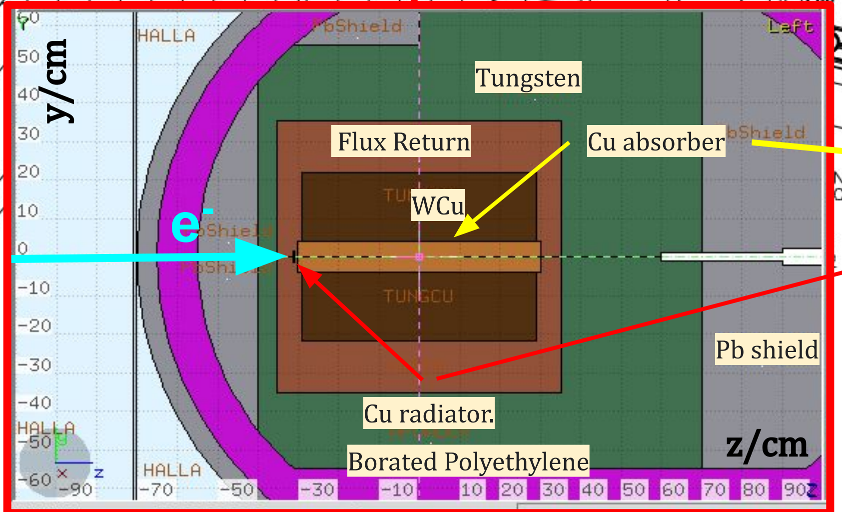
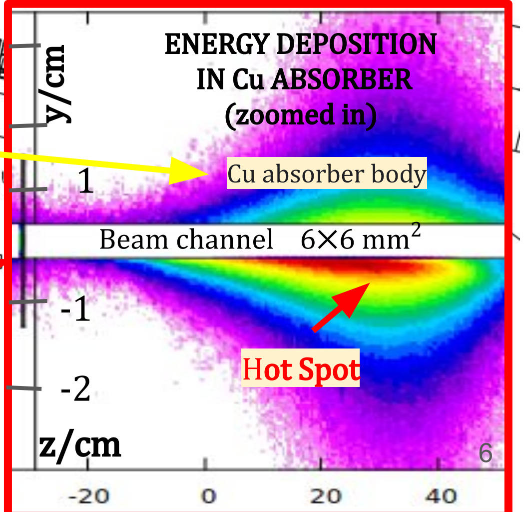
(1) D. Day, P. Degtiarenko, S. Dobbs, R. Ent, D. J. Hamilton, T. Horn, D. Keller, C. Keppel, G. Niculescu, P. Reid, I. Strakovsky, B. Wojtsekhowski, J. Zhang, “A conceptual design study of a Compact Photon Source (CPS) for Jefferson Lab”, NIM 957, 2020.

Possible location for Hall-C CPS clone in Tagger Hall-D.



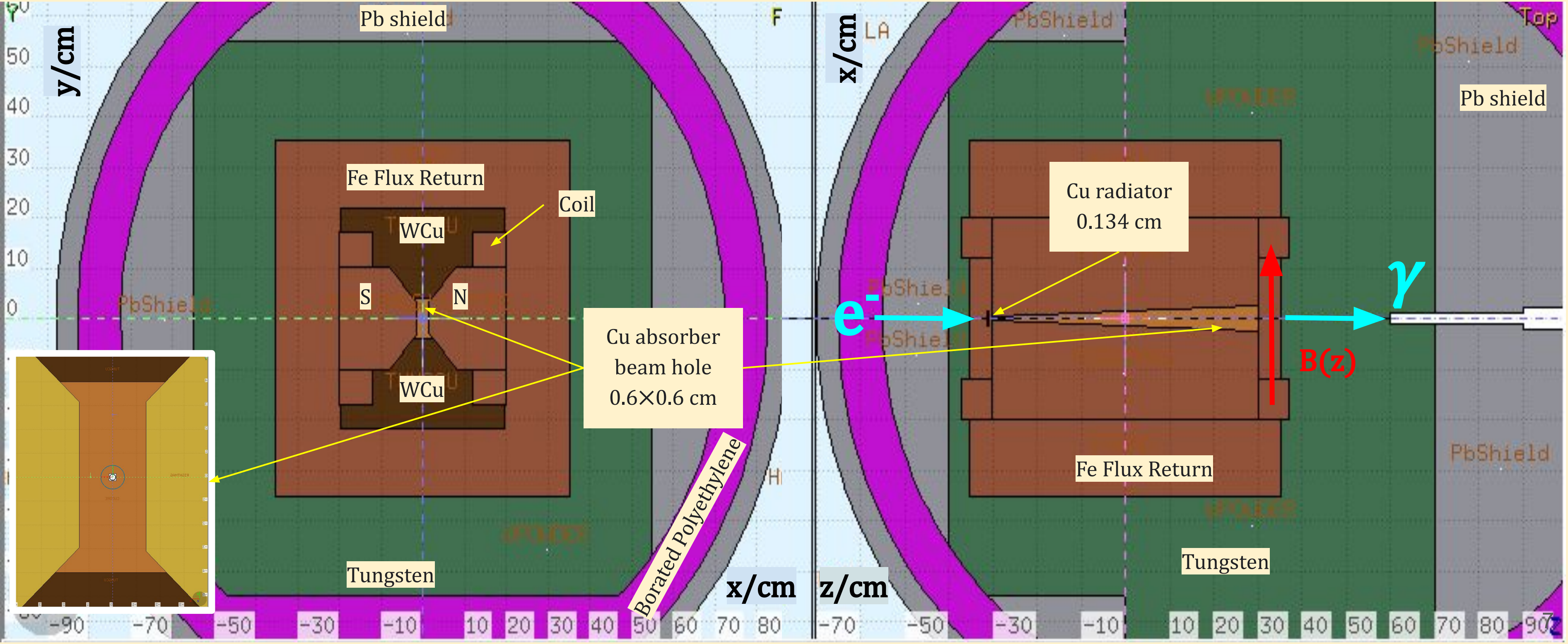




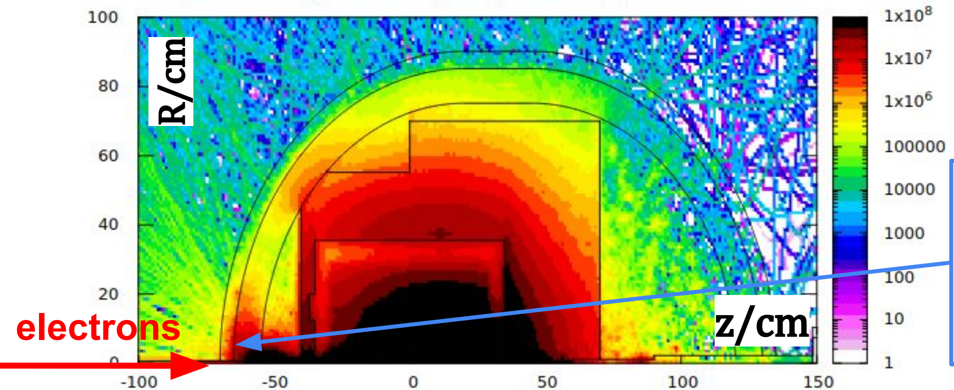


Hall-C Compact Photon Source as a reference for Hall-D

FLUKA model from Gaby Niculescu.

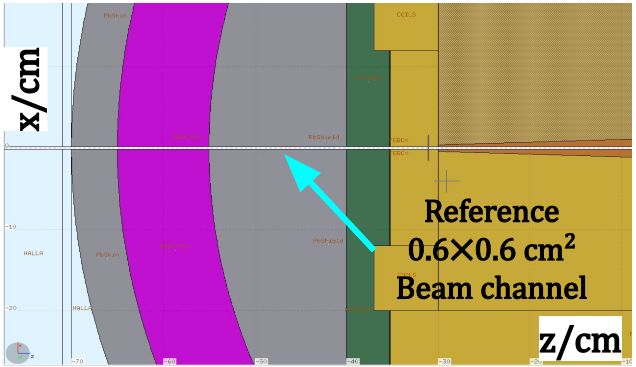


Modification 1: entry hole to meet a wide e-beam FWHM = 0.25 cm.
DOSE rate estimations after T=1000 hrs of 60 kW beam.

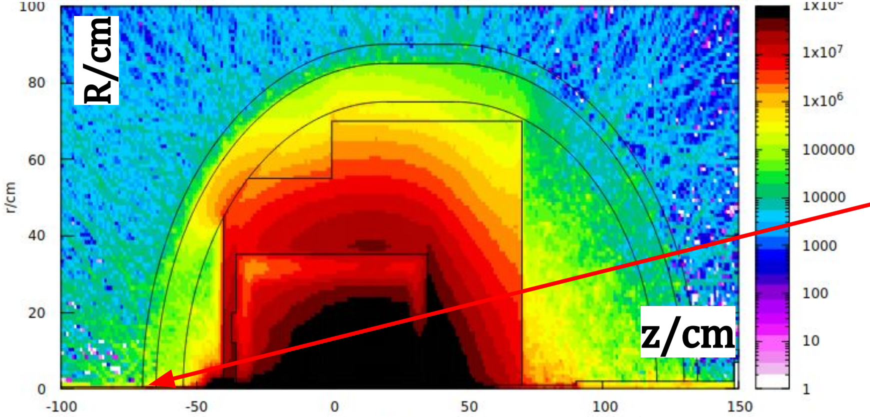


Dose(T+1 hr)
[pSv/s]

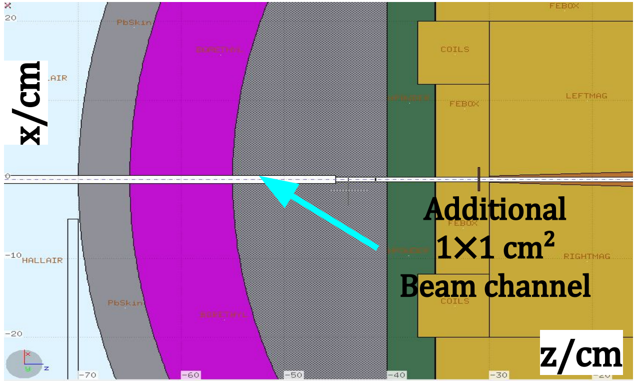
~ 2. E**+6** [pSv/s]
@
I = 2.7 [μA]
=**720** [mrem/hr]



Reference
0.6×0.6 cm^2
Beam channel



~ 2. E**+4** [pSv/s]
@
I = 5.0 [μA]
=**3.6** [mrem/hr]

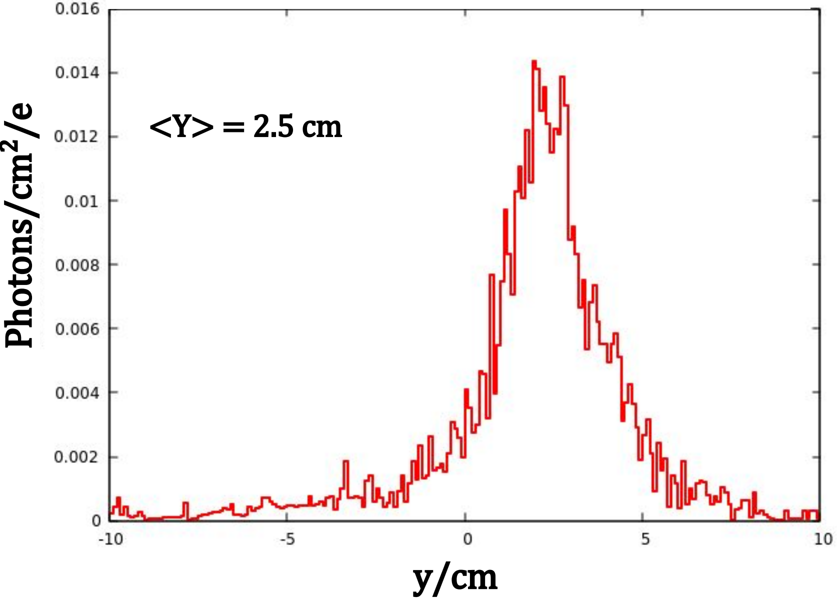


Additional
1×1 cm^2
Beam channel

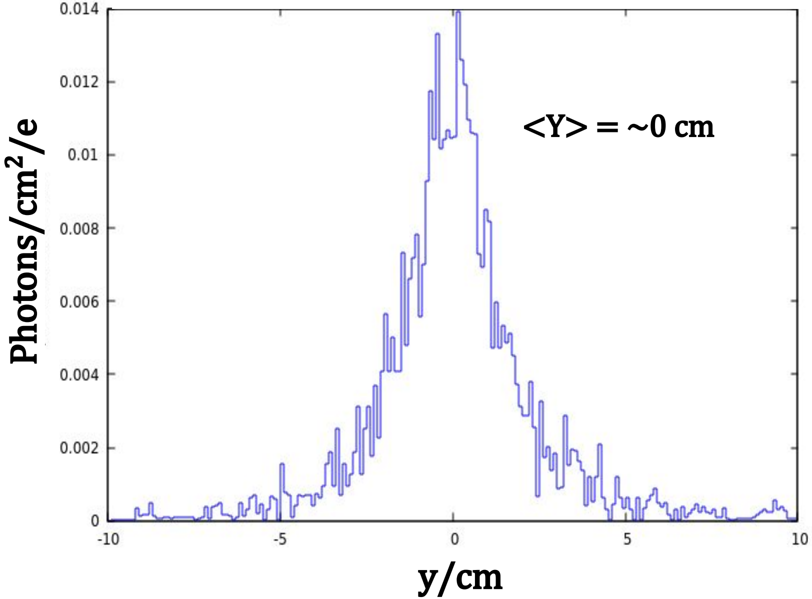
- Beam inlet 1×1×30 cm^3 transitions into beam channel sized as 0.6×0.6 cm^2
- Effect of 30 cm inlet is ~200 times lower Dose at the Upstr. Side; ref.: 5 mrem/hr.

Modification 2: steering magnet at the entry to CPS to recover Photon Beam Profile at KPT.

Reference photon beam profile.



Photon beam profile with steering magnet.



- **Displacement** is caused by **magnetic field upstream** the **γ**-radiator and ~67 m **distance** to KPT.
- ~40% of **photons miss** the Be target of KPT .
- Steering Magnet is included into FLUKA model: B=0.032 T , L=0.5 m.

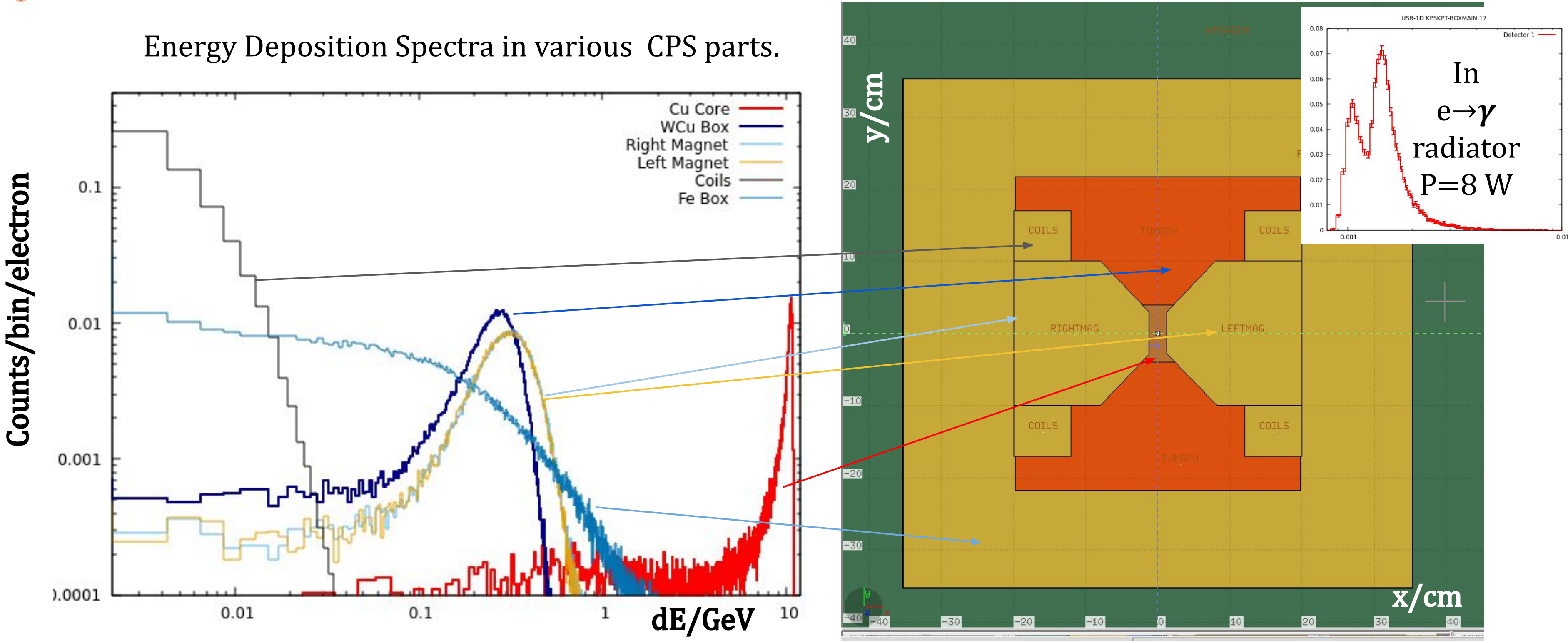
III

Energy Deposition and Temperature in the Hot Spot
vs
Magnet Length and Radiator Materials

Hall-D e-beam parameters : 12 GeV , 5 μA, Gaussian FWHM=0.25 cm;
Beam Entry hole : 1×1 cm^2 → Beam channel : 0.6×0.6 cm^2

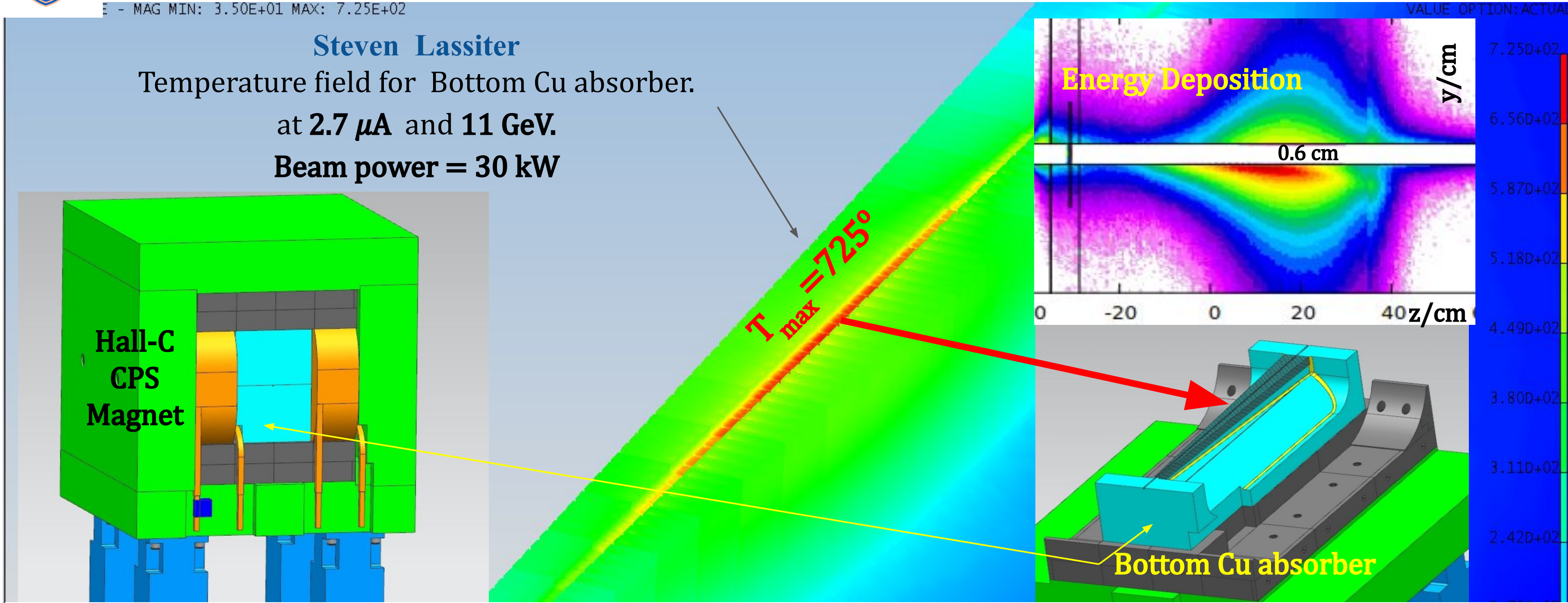
Energy Deposition Spectra in parts of reference CPS at 12 GeV.

Energy Deposition Spectra in various CPS parts.



- Power in Cu absorber: P [W]=**1.E+10[eV/e]** 1.6E-19 [J/ev] 0.6E+19 [e/A/s] 5.E-6 [A] =**50 kW.**
- It is 80% of beam P =V*I= 1.2 E+10 [V] 5.E-6 [A]=**60 kW**. The rest of **10 KW** - in WCu and magnet poles.

Hot Spot Temperature for CPS design from HALL-C .



Steven Lassiter

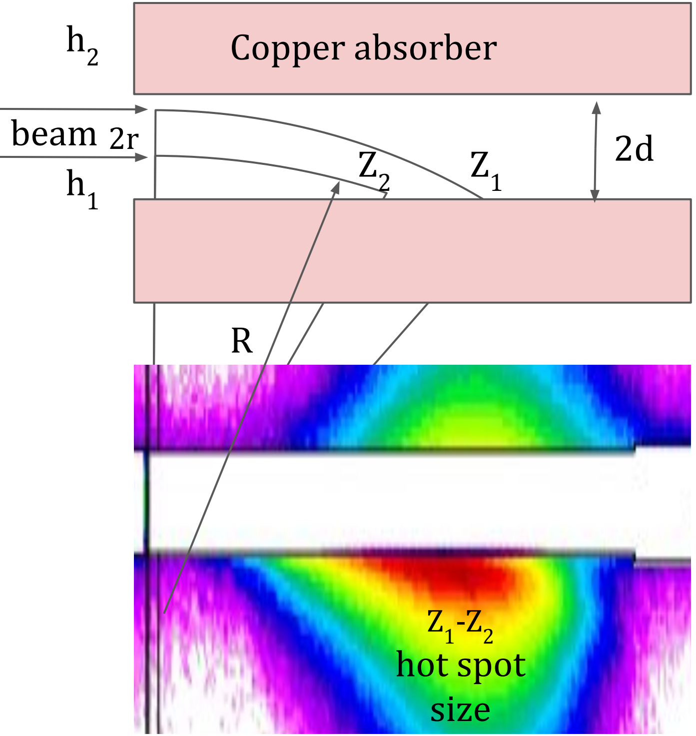
Temperature field for Bottom Cu absorber.

at **2.7 μA** and **11 GeV.**

Beam power = 30 kW

- In this design WCu alloy between coils is replaced with Cu.
- What temperature do we expect at beam power **60 kW ?**
- How can we **respond to** potential **challenges**?

Option 1: Hot spot size vs Dipole Magnet Length and Filed.



From the geometry consideration:

$$Z \cong \sqrt{2Rh}$$

Hot spot size:

$Z_1-Z_2=\sqrt{2R}(\sqrt{h_2}-\sqrt{h_1})$

where

$h_1= d+r$

$h_2= d - r$

2d - beam channel size

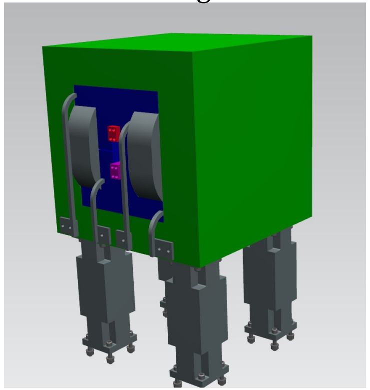
2r - beam raster / size.

- To make the hot spot wider **reduce B(z)** ,
- Reduce “d” if possible, and maximize beam size “r”<”d”.
- At fixed “d” and “r” - increase magnet length and reduce field.

Option 1: **Energy** Deposition **vs** **Magnet Field**.

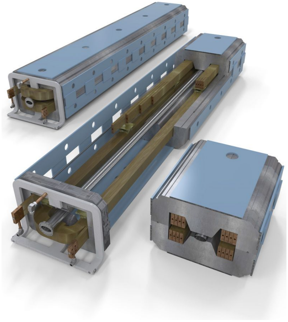
(1 and 2)

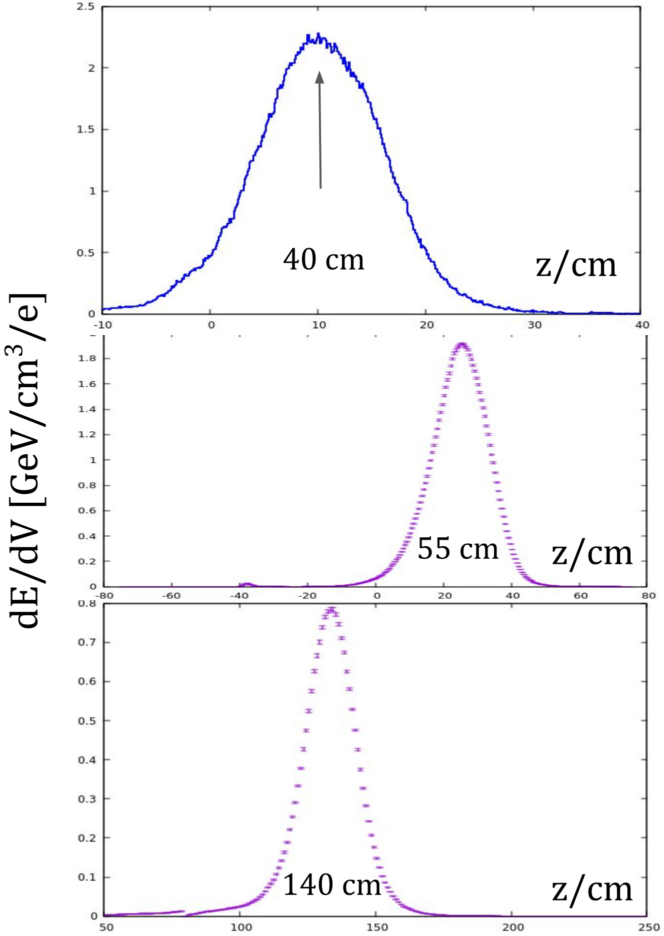
CPS Magnet



(3)

BNL beam-line dipole





(1) Reference

0.75 m × **3. T**

Max

dE/dV=**2.3 GeV/cm^3/e**

(2)

1.5 m × **1.5 T**

Max

dE/dV=**1.8 GeV/cm^3/e**

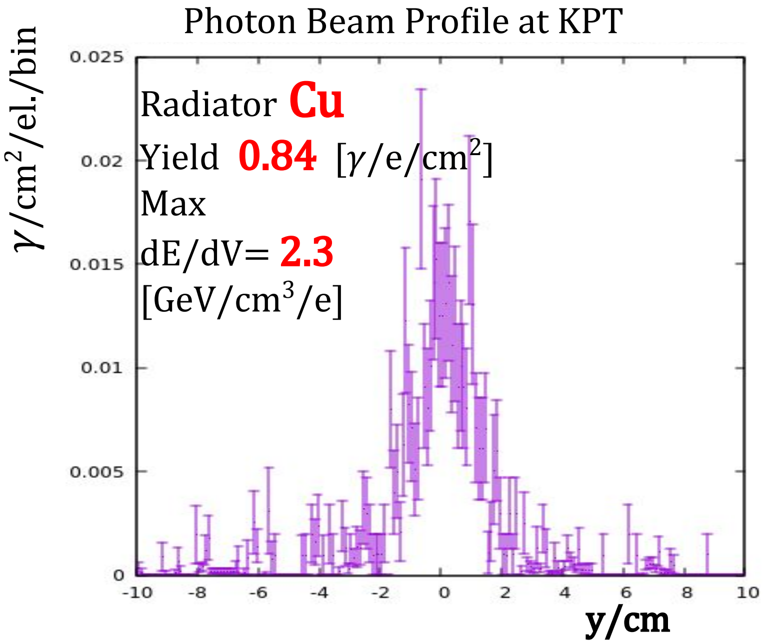
(3)

3 m × **0.35 T**

Max

dE/dV=**0.8 GeV/cm^3/e**

Option 2: **Energy** Deposition **vs Radiator Material**.

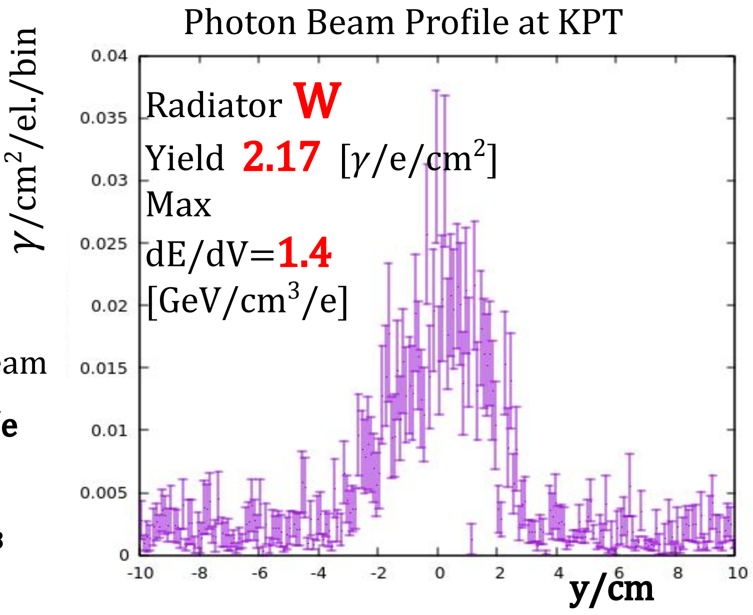


At 5μA current of e-beam

dE/dV=1. GeV/cm^3/e

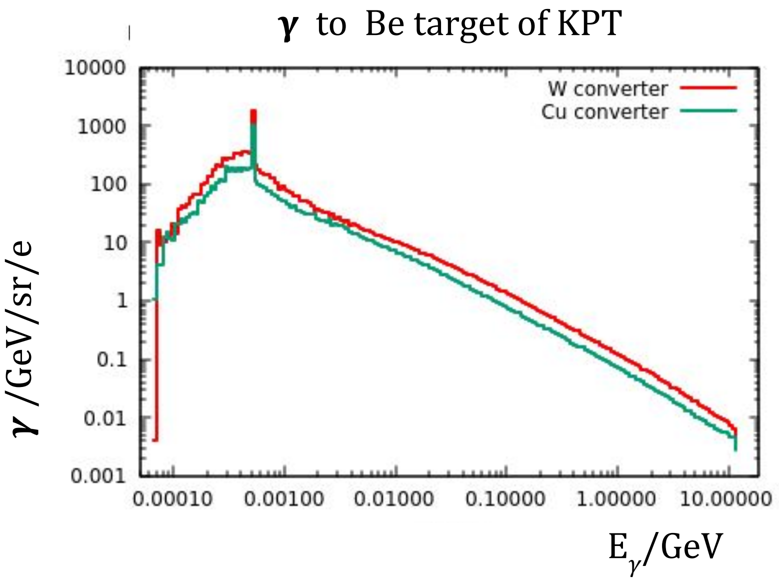
translates to

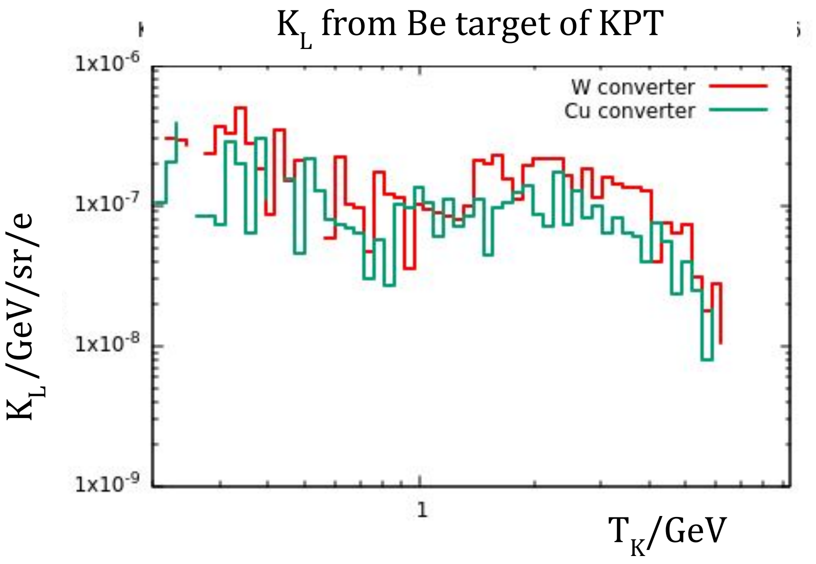
dP/dV = 5. kW/cm^3



- **W**-converter provides × **1.6** **lower** dE/dV in the hot spot and × **2.6** **higher yield** of photons.
- We may have **factor 2.6 × 1.6 = ~4** to **scale down** dE/dV in the "**hot spo**t" .
- However photon beam is **wider**. What is photon **energy spectrum**?

Energy Spectra of $\boldsymbol{\gamma}$'s and K_L's in KPT.


$\boldsymbol{\gamma}$ to Be target of KPT


K_L from Be target of KPT

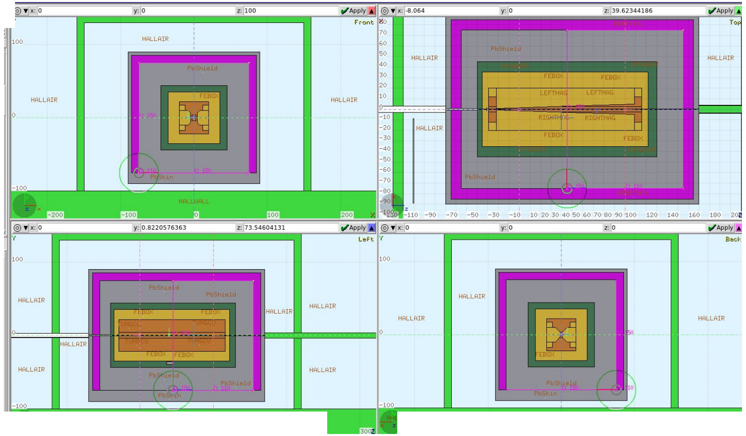
- K_L-and γ-spectra form W- and Cu-radiators are **similar**.
- **W**-radiator **yields** 1.6 times **more** K_L .
- Other radiator **materials and sizes** may be tested, including a **thisker Cu** converter.

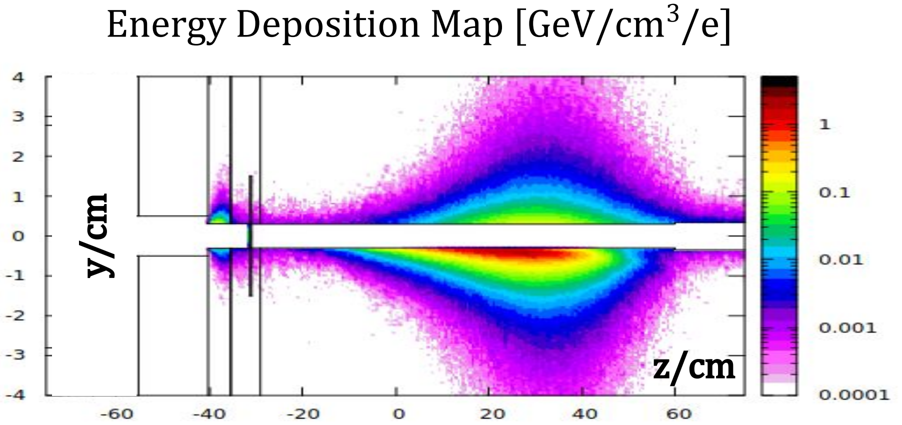
IV

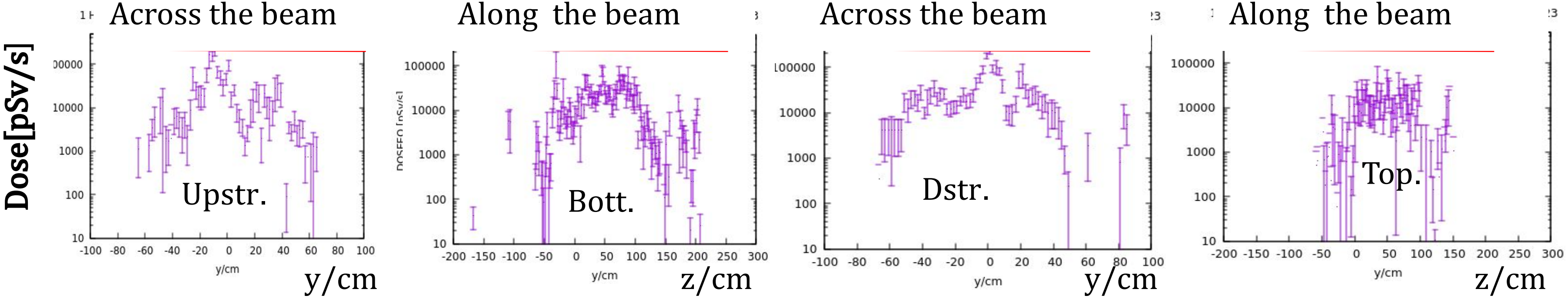
Radiation Safety.

Example of the Dose Rate after 1000 hours of operation followed by a 1 hour pause.

Example: Dose rate for CPS with 140 cm Dipole at ½ nominal field map.



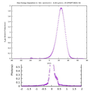

Energy Deposition Map [GeV/cm^3/e]


Across the beam

Along the beam

Across the beam

Along the beam



1. **Simpler magnet poles may be used for twice lower uniform field.**
2. **1 hr Dose at all surfaces is below 72 [mrem/hr] = 2.E+5 [pSv/s]. Reference value: 5 [mrem/hr].**

What we need to proceed with CPS design.

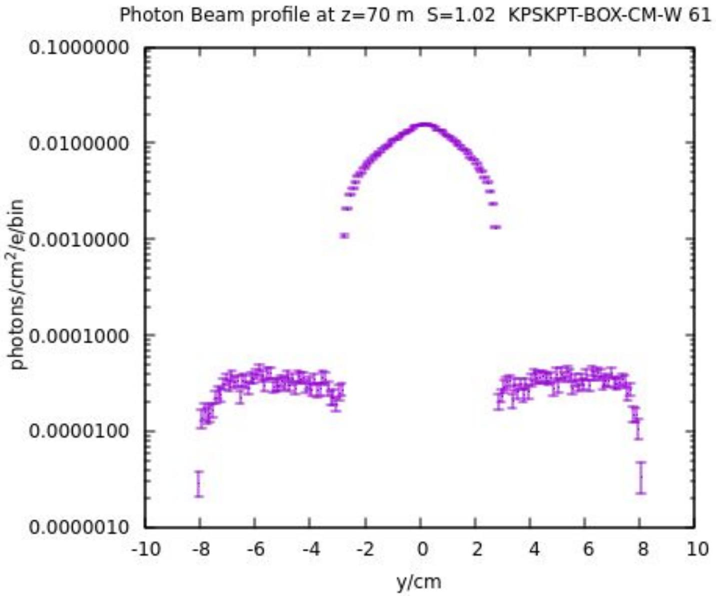
- Develop **Fluent** model with boundary conditions **and cooling lines.**
- **Mesh** for T^o-map should scale in ***mm*** (beam size).
- **Thermal Map and Stress** calculations using Energy Deposition Map from FLUKA.
- A simplified **FLUKA model** is prepared.
- Model is exported as ***.scad** file.

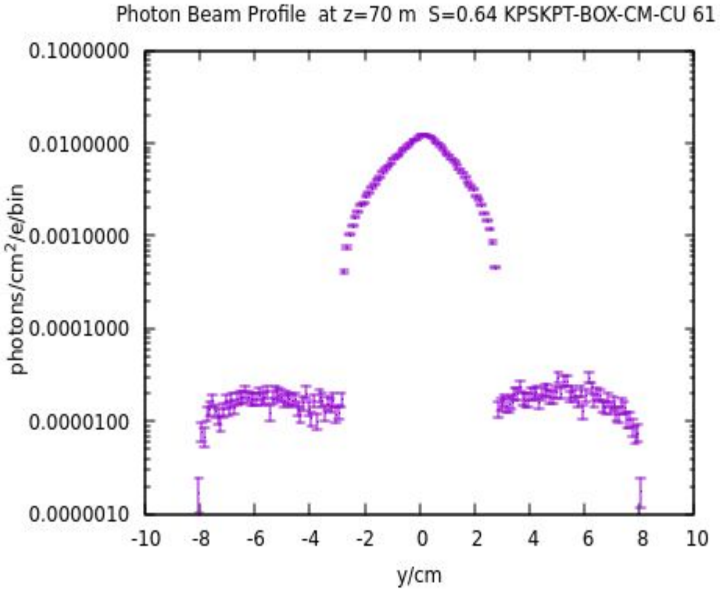
Conclusive remarks

- With **reference magnet** we hopefully may respond to a **possible T°-challenge** :

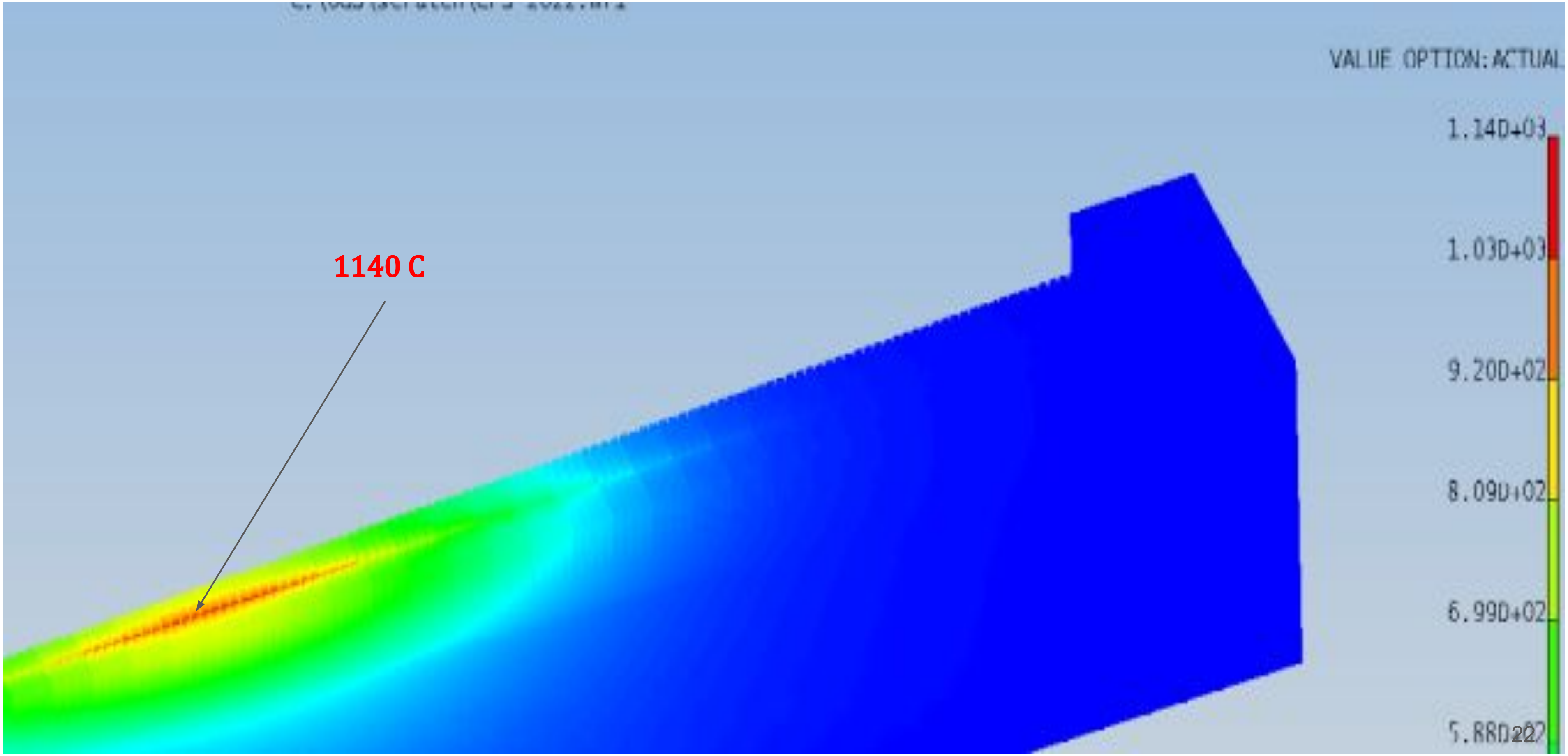
1. Uniform gap between poles =4.8 cm and **lower** B ≤ 1.5 T . =>
2. **Absorber** of uniform 5×8 cm^2 ×-section **with cooling pipes.**
3. Converter **material**.

- **Alternative** option is **increased magnet length** and reduced B ~0.3 T.
- **Dose rate** may be **below 50 mrem/hr** in all cases.


Photon Beam profile at z=70 m S=1.02 KPSKPT-BOX-CM-W 61


Photon Beam Profile at z=70 m S=0.64 KPSKPT-BOX-CM-CU 61

Absorber Bott Half of Absorber. NO good thermal contact with Top Half.



1140 C

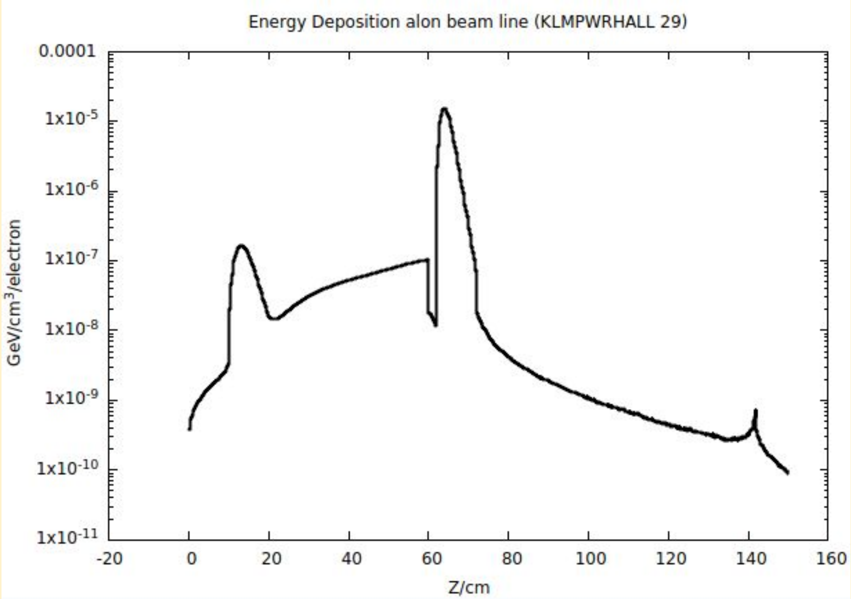
What we learn from the presentation of   Steven Lassiter.

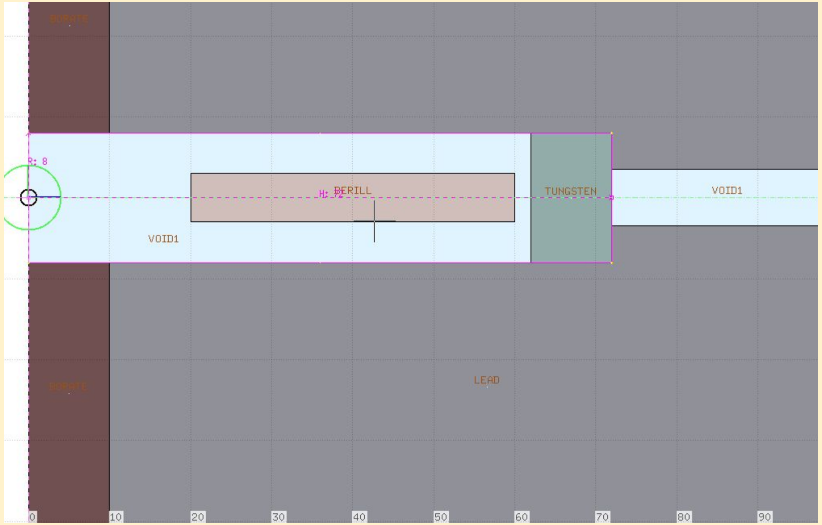
- If **top half of absorber** does not make good **<u>thermal contact</u>** with **bottom half**, temperature **rises** in bottom half up to **1140 C** !
- **Boundary conditions** are not realistic, waiting on **Fluent models** to determine proper BCs.
- **Bottom half will be sitting** on W-Cu blocks. **Top Half** will have W-Cu blocks **on top** also.

What to do ASAP.

- **Thermal Map** **and Stress** to be addressed by Hall-D ASAP.
- A simplified **FLUKA model** and exported   ***.scad**   file is prepared.
- **Cooling lines** to be included. **Mesh** for T-map to scale in *mm* (beam size).

Energy Deposition Profile along the KPT axis @ R<3 cm





- There is a **very hot spot** in the Tungsten cylinder

Status and Future

- Simulation with finer granularity is done and **numerical file is provided** for

  20 < Z < 80 cm in 1 cm bins 0 < R < 10 cm in 1 cm bins.

- **Calculation time** is of 24 hrs per 80000 primary electrons.
- More realistic beam line – longer calculation time.
- A new **Photon Source** source Model –

  – “gn_CPS30_mkIb_power2k.inp” –

  received from H. Egiyan →

```
[baturin@hallal1 KLMGSOU]$ flair gn_CPS30_mkIb_power2k.inp
```

is **stored for** further **development** :

```
[baturin@hallal1 KLMGSOU]$
-rw-r--r--  baturin clas   magfld.f
-rw-r--r--  baturin clas   gn_CPS30_mkIb_power2k.inp
-rw-r--r--  baturin clas    cps_mag01_30.txt
```