Compact Photon Source for Hall D at JLab. Design and simulation using FLUKA.

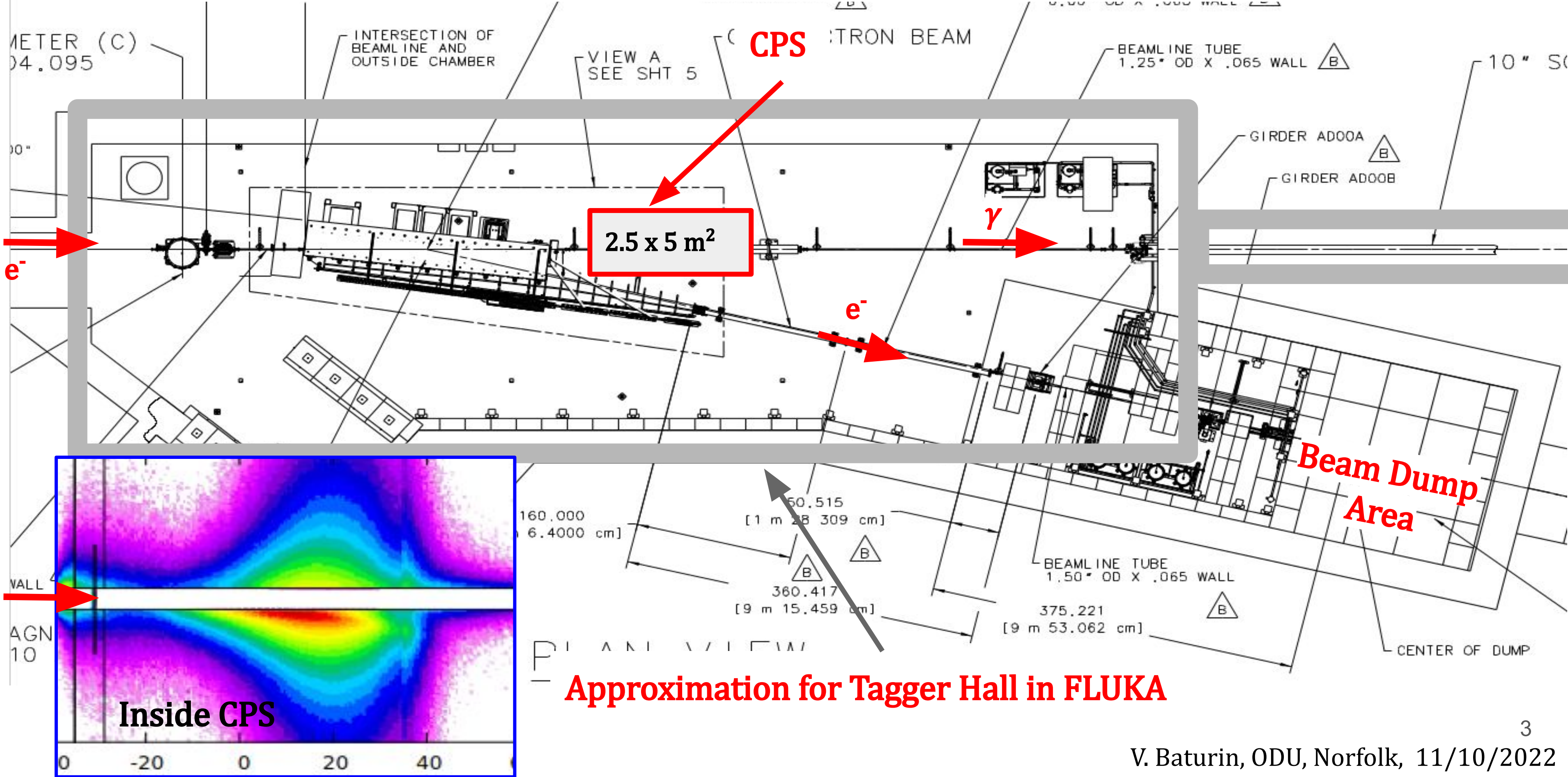
For KLF Collaboration
V. Baturin , Old Dominion University, Norfolk,VA.

OUTLINE

1. CPS with copper Absorber. Design and Location.
2. Energy deposition and Absorber temperature.
3. Photon Beam quality.
4. Prompt Dose and Activation around CPS and Tagger Hall.
5. Magnet irradiation and lifetime.
6. Tritium contamination in soil and cooling waters.
7. Conclusion and Outlook.

CPS as adjustable unit with 5 degrees of freedom.

CPS in Tagger Hall



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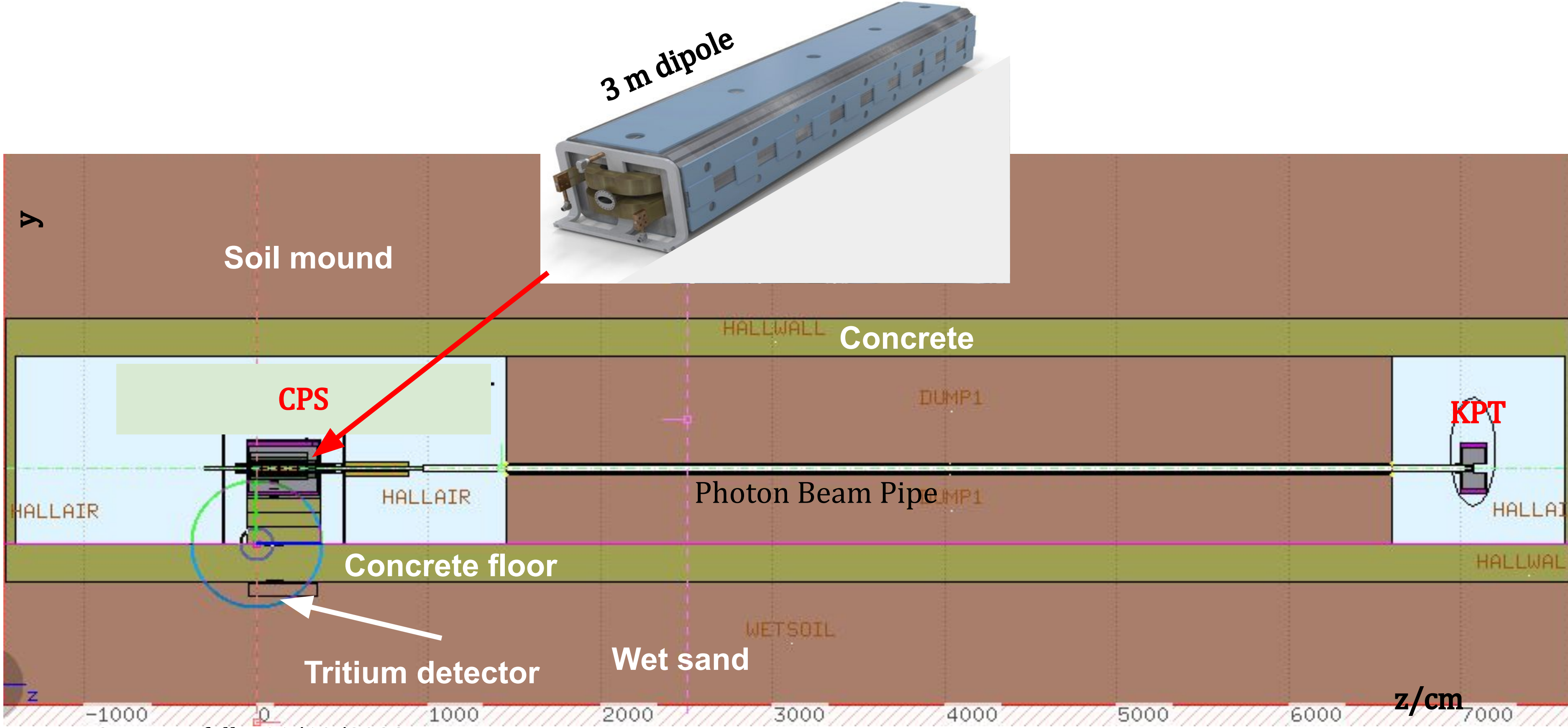
CPS, Tagger Hall, and KPT in FLUKA model.



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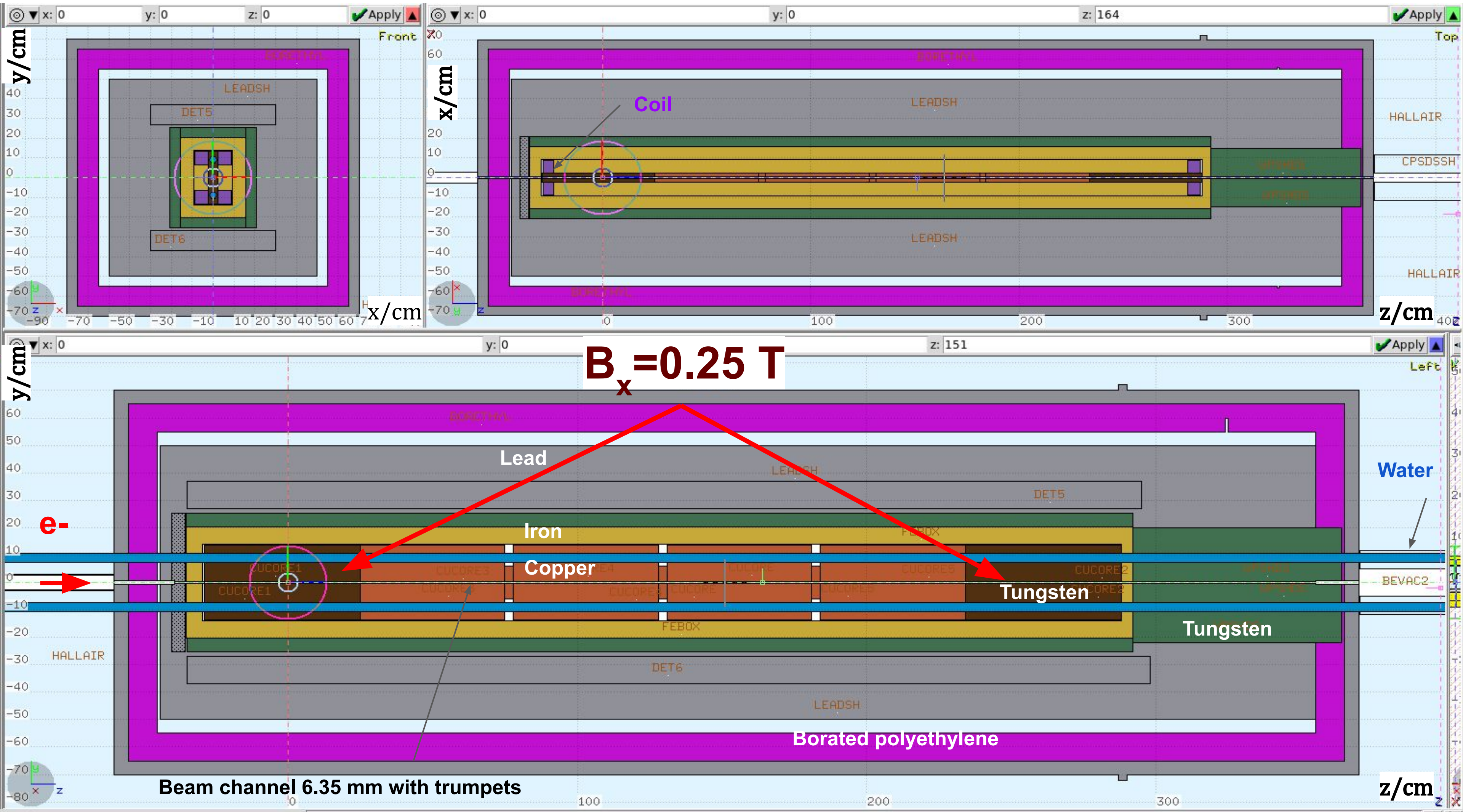
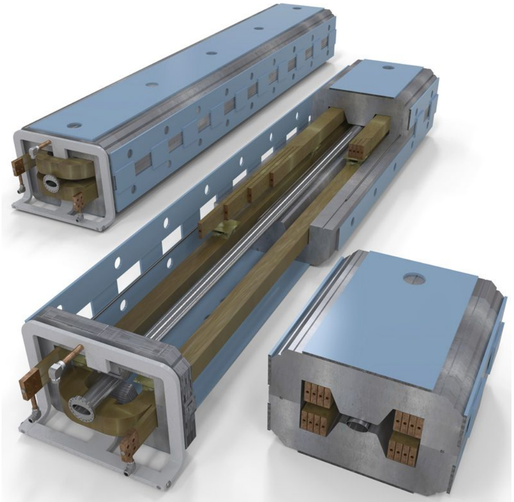
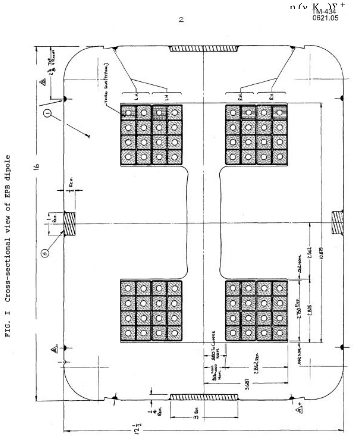


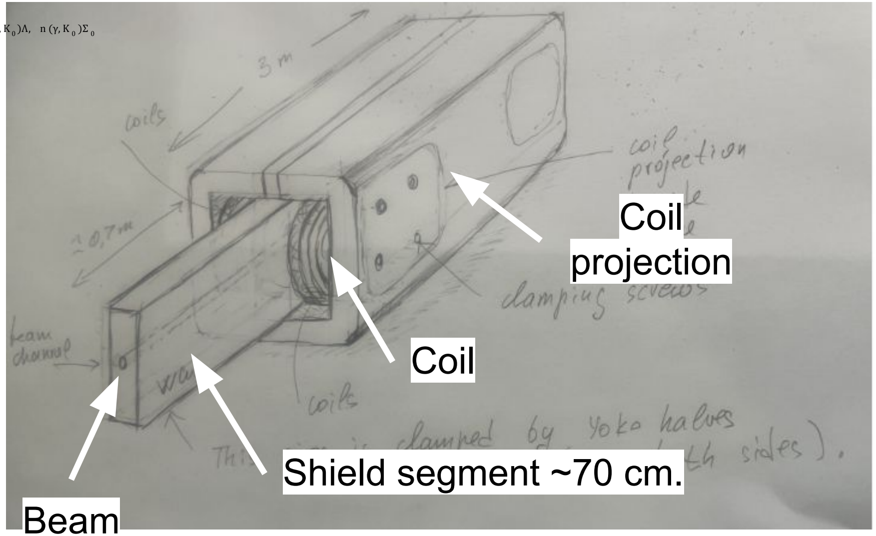
Front
Top
Left
y/cm
x/cm
z/cm
Coil
LEADSH
DET5
DET6
HALLAIR
CPSDSSH
BEVAC2
FEBOX
CUCORE1
CUCORE2
B_x=0.25 T
Lead
Iron
Copper
Tungsten
Water
e-
Borated polyethylene
Beam channel 6.35 mm with trumpets

CPS magnet. Advantages of 3 m long yoke.



Fermilab Beamline 1.5×3 Tm dipole





1. Thick **Iron shield** layer around the absorb
2. Precision **housing for all parts** forming the d=6.35 mm channel **including** US and DS **shield segments** .
3. **Compact Portable photon** Source. Assembling and channel **alignment at a bench**.
4. In hall **alignment with 5 DOF** only; othervices => 5 pieces with 25 DOF.
5. **Adjustable gap** between poles –made of two halves– spacer; => wider absorber; access from sides.

Energy deposition
and
Temperature of CPS components.

Electron beam 5 μA, Gaussian FWHM=2.5 mm.

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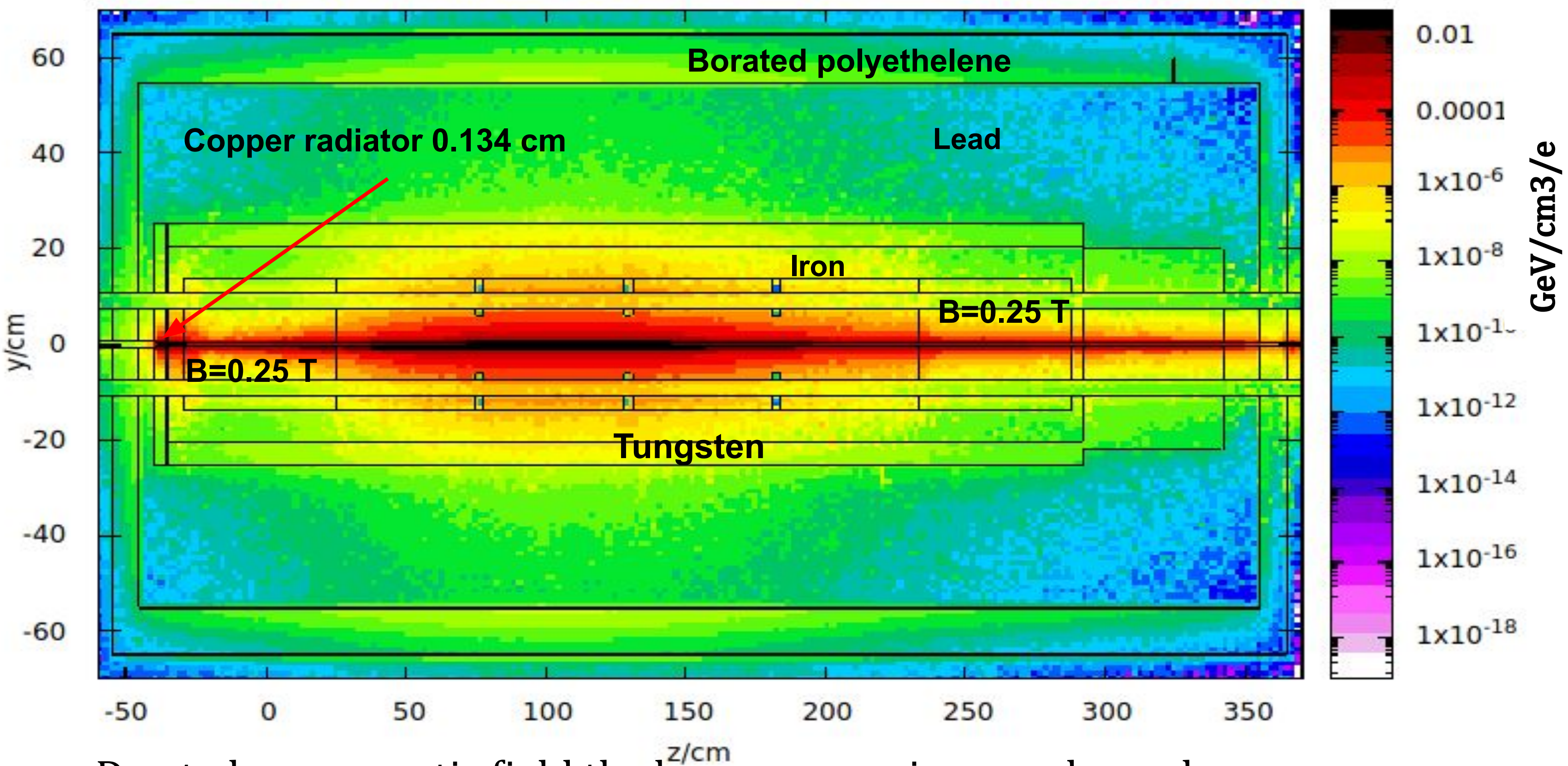
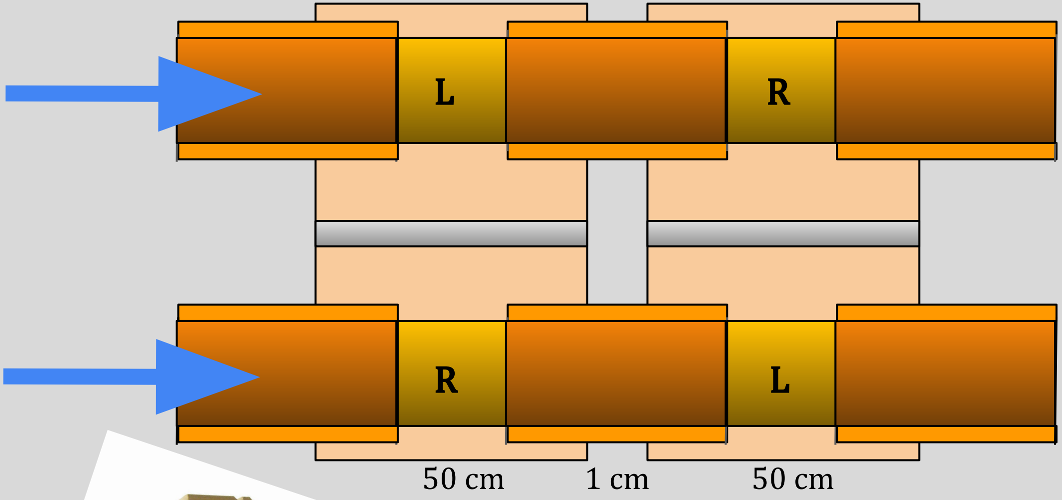
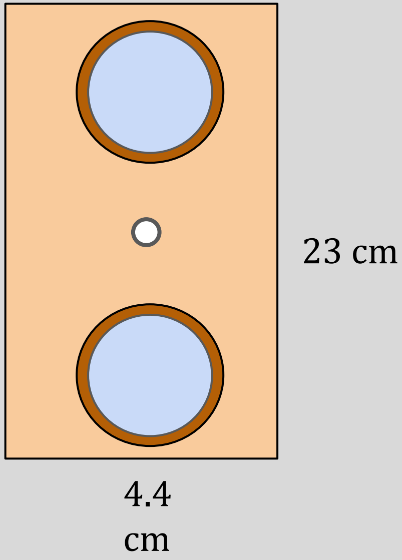
Energy Deposition in CPS .



- Due to low magnetic field the beam energy is spread over large area.
- Maximum Energy Deposition is ~0.35 GeV/cm^3/electron. Temperature?

Segmented Copper Absorber. Possible solution.





Segment $4 \times 20 \times 50$ cm^3 with **round** beam **hole** = >avoid problem with thermal contact between parts.

Segments are connected by fittings with **left/right-**hand threads; may be soldered.

Provides direct **copper-water contact** in each segment => no interface; better cooling.

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Power breakdown between CPS components .

CPS part	GeV/e	kW/5 μA
DS Shield (W)	0.063	0.316
US Shield (W)	0.033	0.163
Side Shield (W)	0.013	0.064
Top Water Pipe	0.001	0.005
Bottom Pipe	0.001	0.006
Magnet Pole Right	0.322	1.610
Magnet Pole Left	0.321	1.619
Coils	0.058	0.289
Magnet Yoke	0.101	0.504
Lead Shield	0.006	0.032
Polyethylene (B)	0.002	0.011
Lead Skin	0.001	0.004
Converter (Cu)	0.002	0.010
Total	0.923	4.620

Segment	GeV/e	kW/5 μA
1 W/Cu	0.230	1.151
2	2.013	10.077
3	4.743	23.744
4	2.034	10.183
5	0.385	1.929
6 W/Cu	0.164	0.822
Radiator	0.002	0.010
Total	9.571	47.916

Energy deposition map in “hot” segment of Absorber.

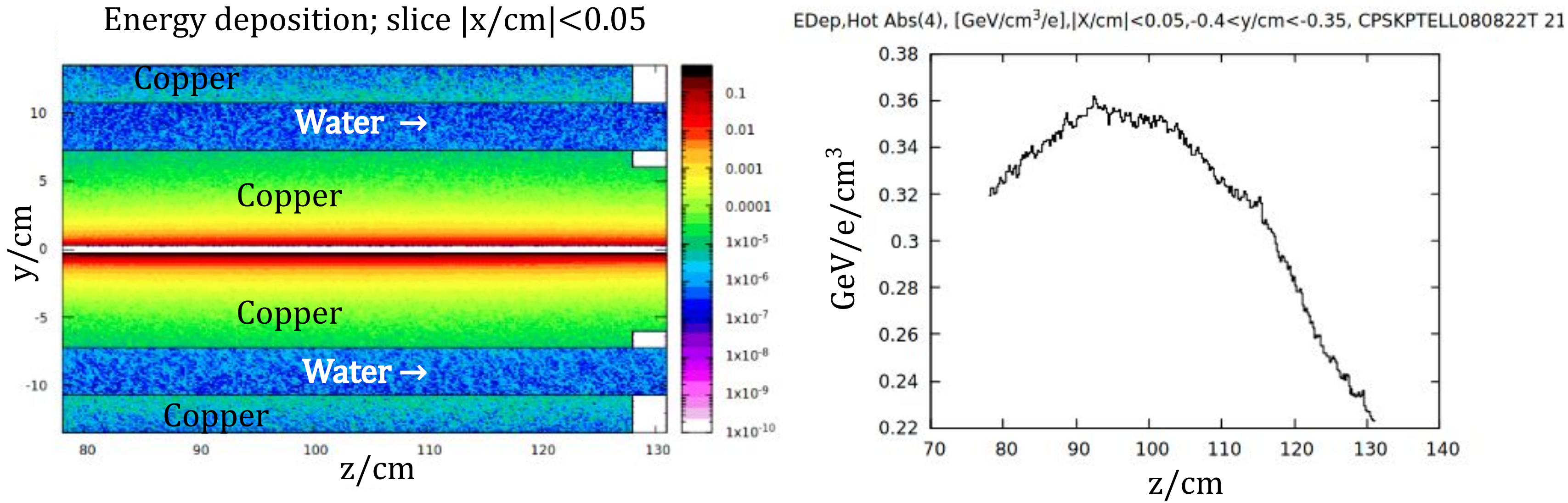
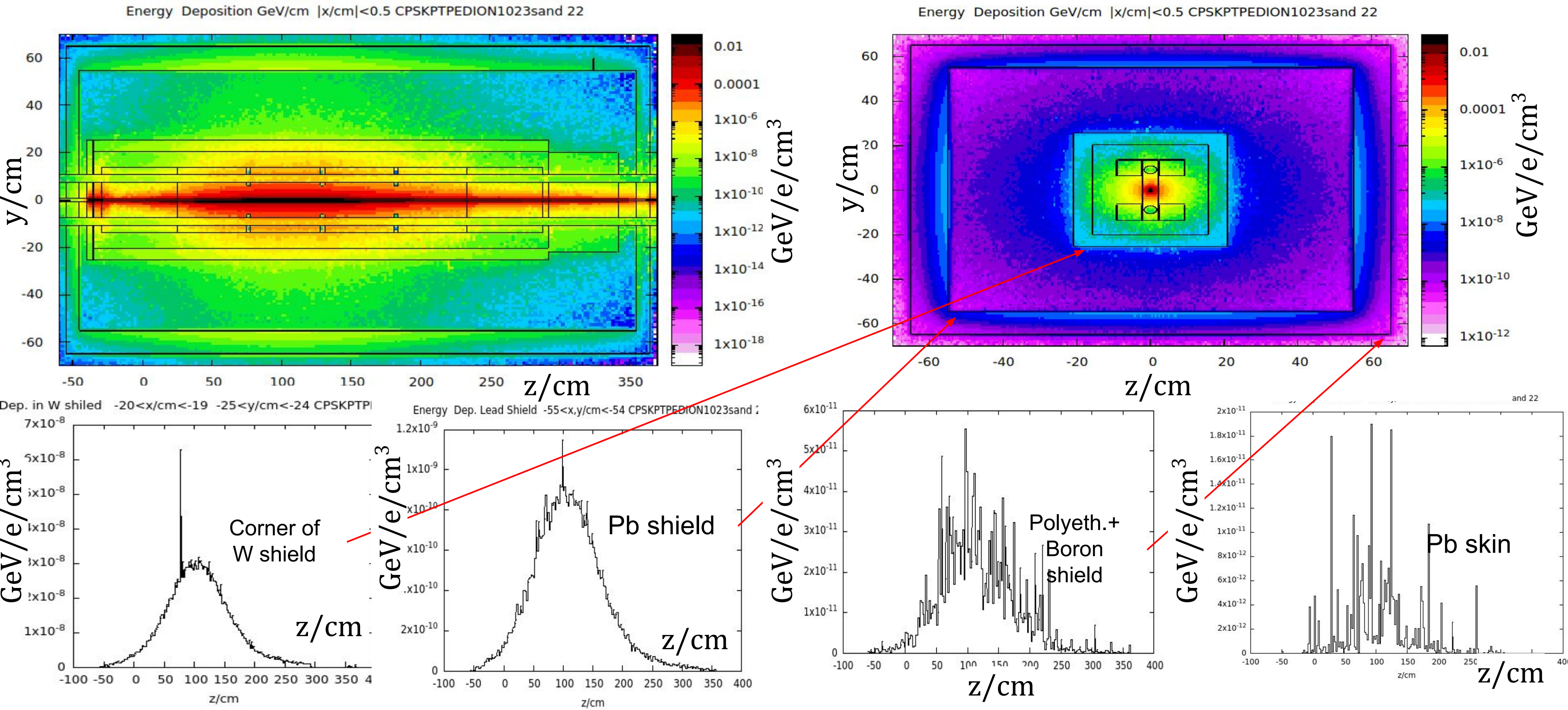


FIG. 11. Left: Energy deposition map in the “hot” segment. The mesh is sized as $(x \times y \times z) = (0.5 \times 0.5 \times 2)$ mm^3. Horizontal scale – horizontal in hall coordinate z along the beam line in cm. Vertical scale – vertical in hall coordinate y in cm. Color scale – energy deposition in GeV/cm^3/e. Right: Energy deposition profile in “hot” segment in a skinny layer of the channel bottom: $|x| < 0.5$ mm and -4 mm $< y < -3.5$ mm.

- ANSYS calculation are done by Tim Whitlatch.
- **Copper** does not melt. Maximum surface **temperature = 200 C°**.

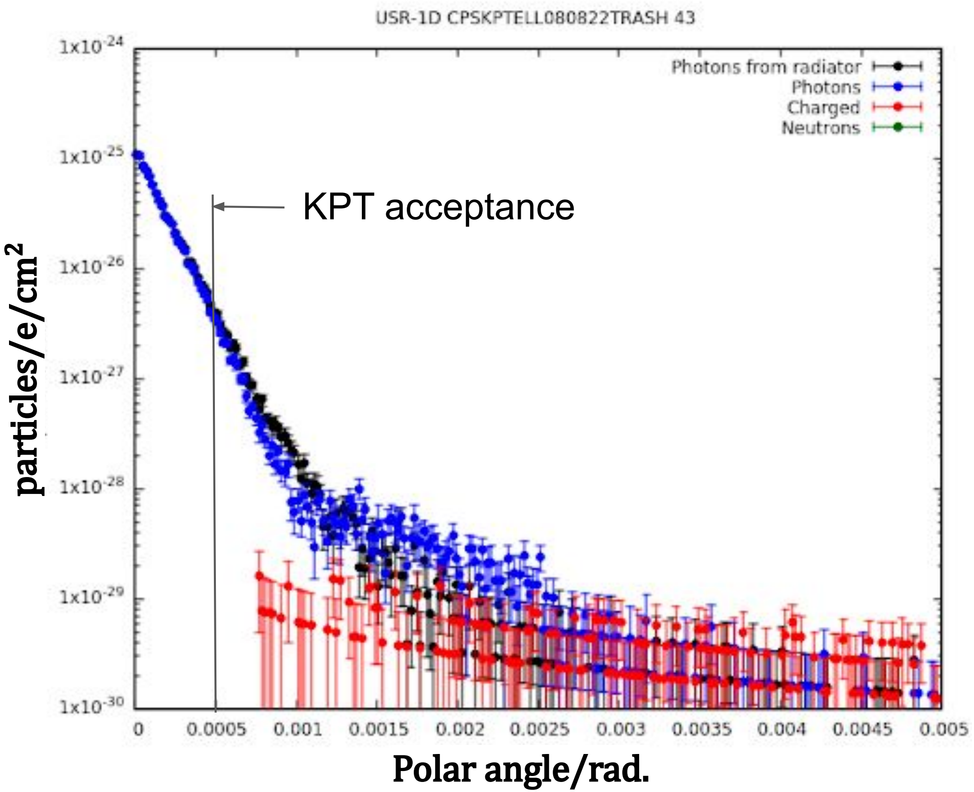
Energy Deposition Map in CPS shield layers.



- ANSYS calculation in progress – Tim Whitlatch.
- What is **lead temperature?** Can be **tungsten replaced** with lead?

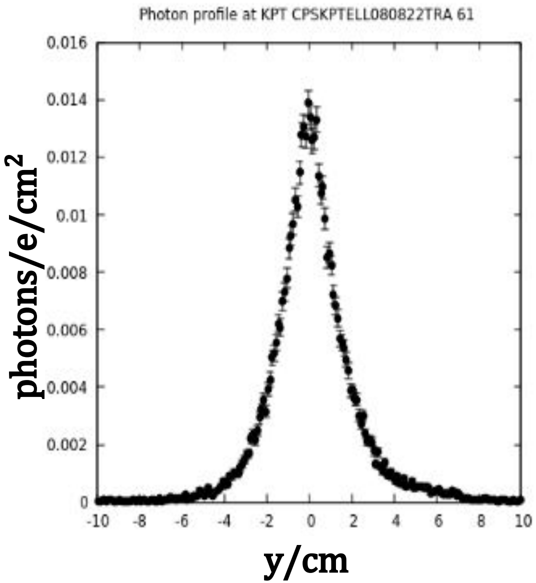
Photon Beam Quality

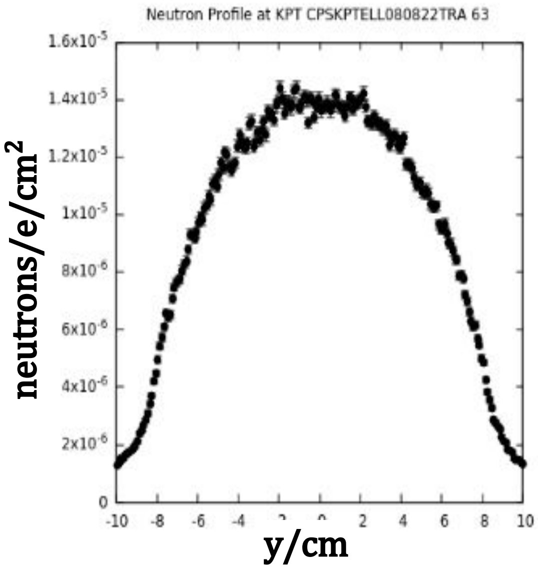
Particles exiting from the CPS ; angular distributions.

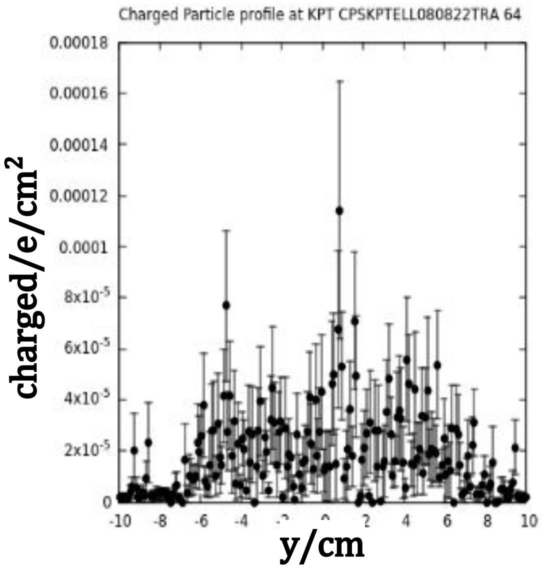


- Photon beam at the CPS exit looks very clean (~1.E-3).
- What happens to the beam after 67 m long beam line ?

Particles entering KPT ; vertical profiles .



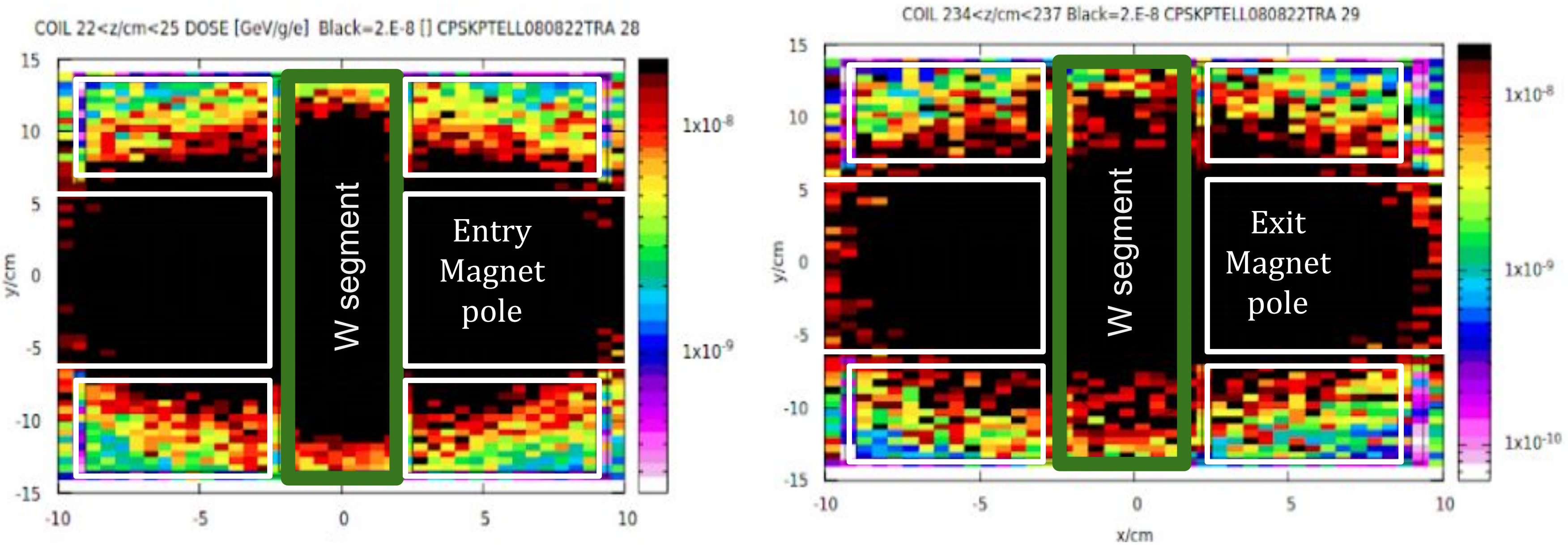




- After 67 m of beam line the total **background** of charged particles and neutrons is of **0.5 %**.
- KPT target acceptance r=2.5 cm; **80%** of photon beam hits the target.
- Photon beam **intensity** is ~**3. E+13 photons/s**.

Magnet performance.
Coil insulation lifetime

Prompt Dose in 3 cm long hot areas of two magnets.



- Maximum dose 2.E-8 [GeV/g/e] = 3.2E-15 [Gy/e] ; (× 1.6E-7 Gy/(GeV/g)).
- At 5 μA beam intensity = 3.E+13 [e/s]. Dose rate = 3.2E-15 [Gy/e]×3.E+13 [e/s] ≅ **0.1 [Gy/s]**.
- Kapton withstands **1.E+7 [Gy]** => Coil **Lifetime** ~1.E+8 [s]=**1160 days** of continuous operation.
- Compare to lifetime of 3 m coil : = ~**25 days** ; ~120 days using fiberglass cloth.

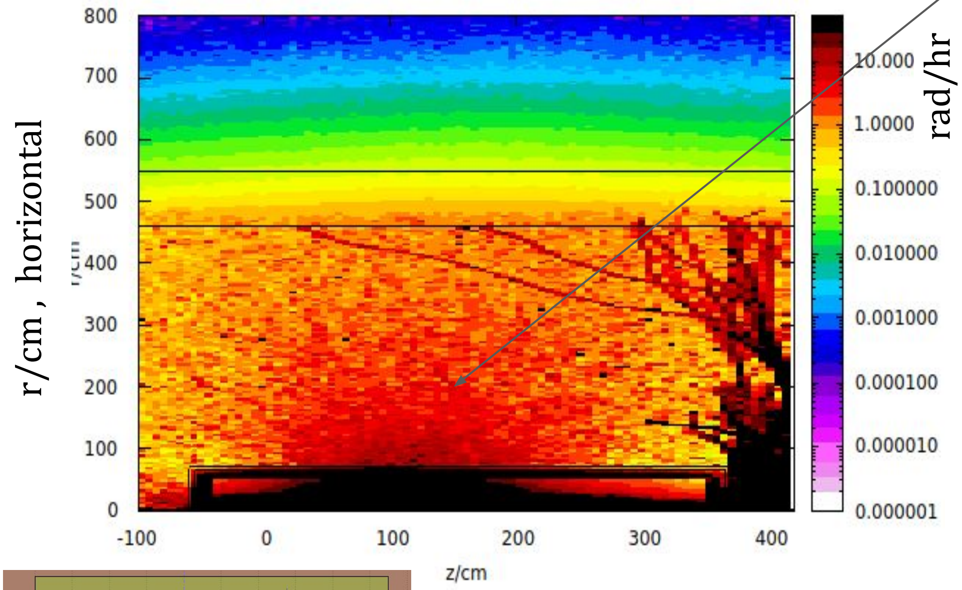
Prompt Dose and Activation around CPS

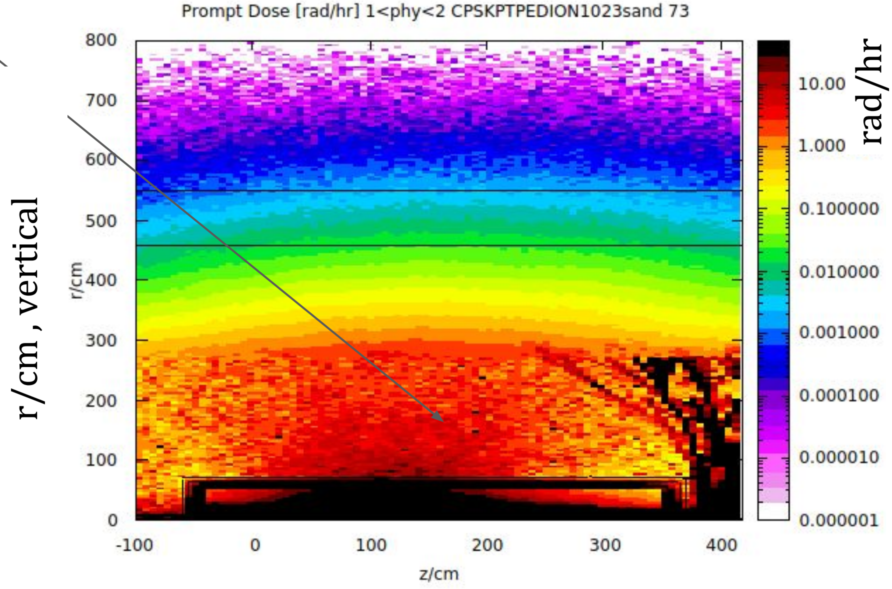
Prompt Dose Rate.

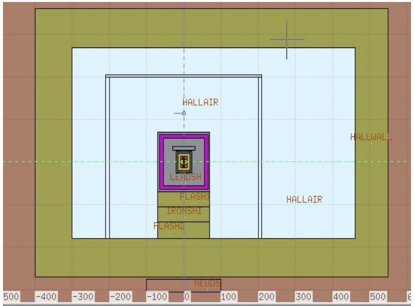
Horizontal profile

~10 rad/hr

Vertical profile

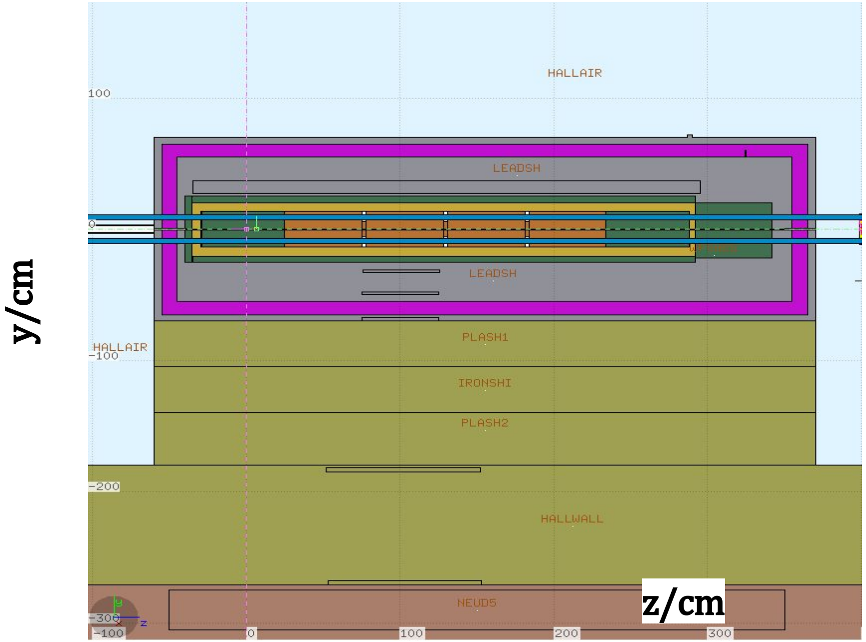


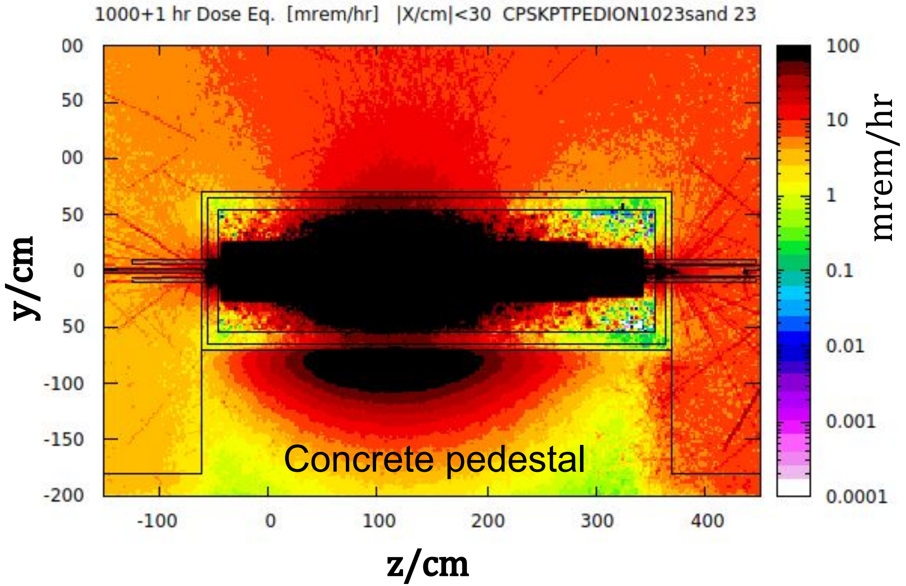




- Maximum prompt dose rate at the CPS surface is of 10 rad/hr.
- May be reduced via shield shape optimisation.

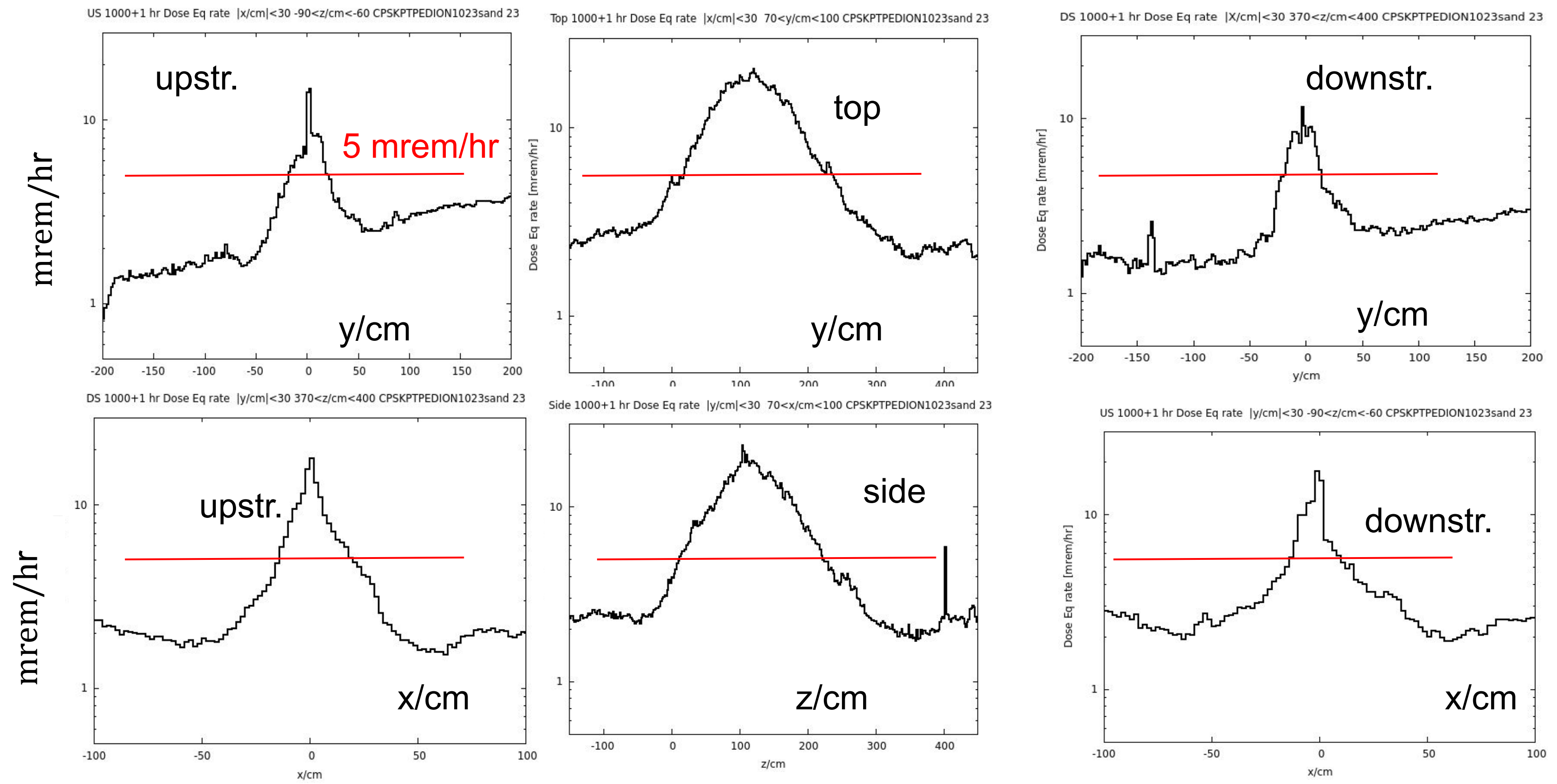
Dose Equivalent after 1000+1 hrs.





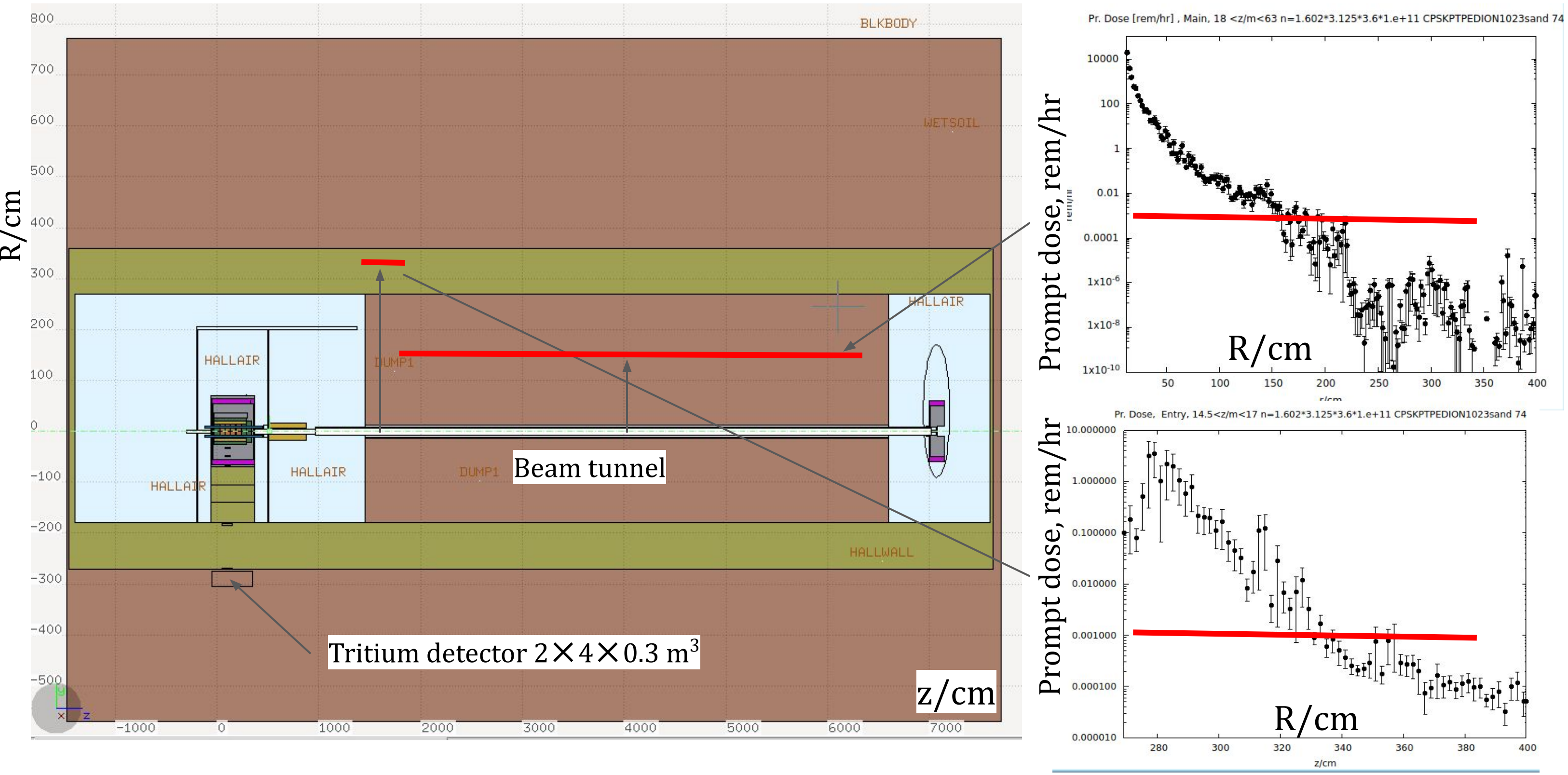
- Higher dose rate at positive y are likely due to the hall ceiling.
- Dose equivalent profiles along surfaces – at the next slide.

Dose Eq. profiles after 1000+1 hrs.



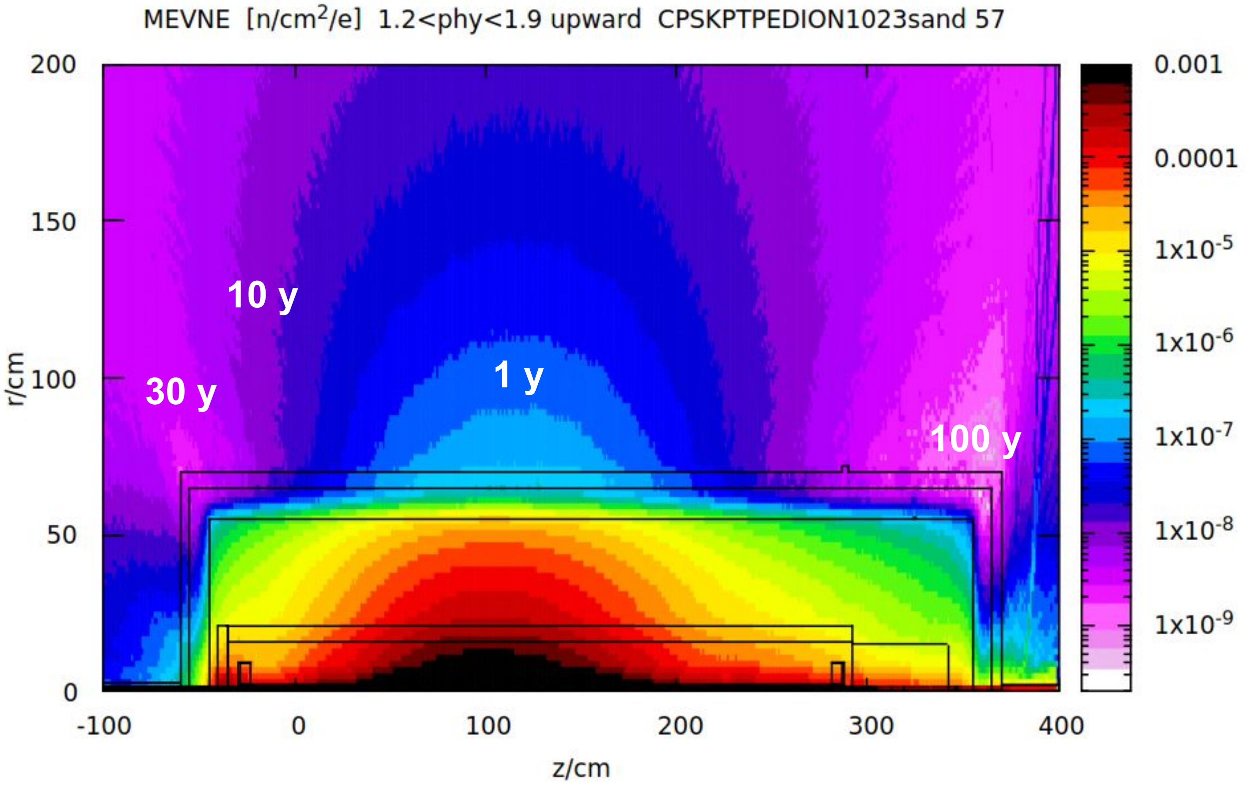
- Some of these profiles are included into Overleaf document.

Prompt Dose between Tagger hall an KPT



- Prompt dose is below **1 mrem/hr** at R = ~3 m in Tagger hall and R=~200 cm in Tunnel.
- Next slide - tritium in ground waters.

One MeV neutron equivalent flux and silicon lifetime.



- Maximum fluence at 1 foot from the middle of the CPS surface ~10^{-7} n/cm^2/e.
- At 5 μA corresponds to the silicon lifetime ~ 1.2 year (critical integ. flux 10^{+14} n/cm^2)

Tritium activity in Soil
and
Cooling Water

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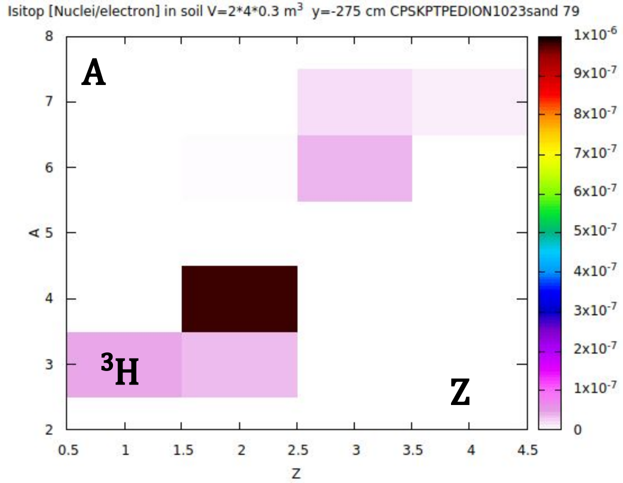
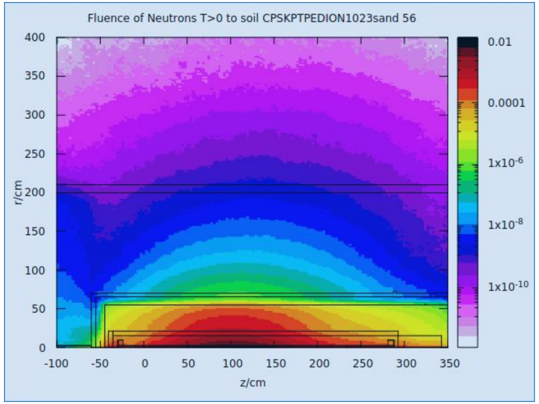
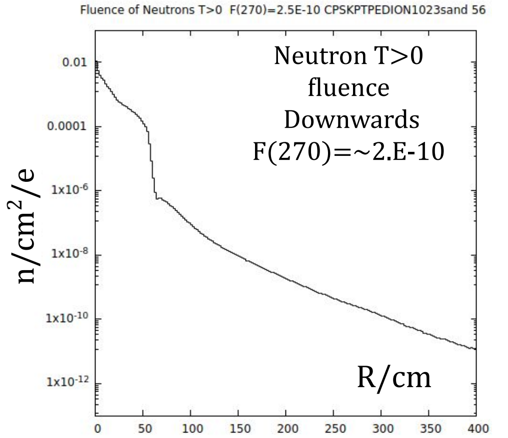
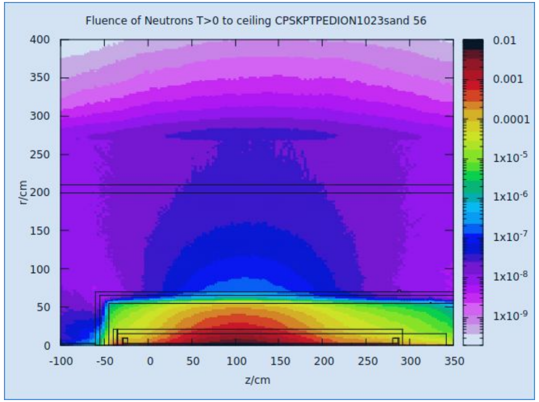
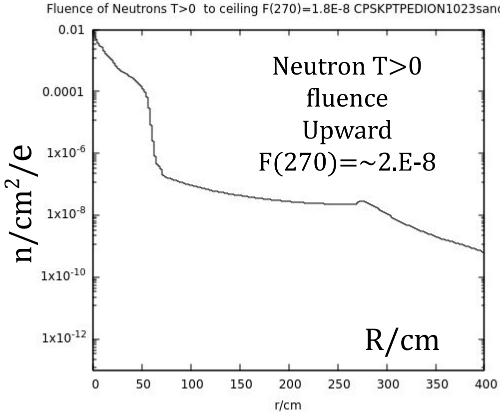
Neutron fluence and Tritium in ground ($V=2.4\ m^3$) waters.











Yield of ^3H in $V=2.4E+6\ cm^3$ of wet sand is ~1.E-7 [T/e].
Number of T nuclei produced in one year: =
N_T=1.E-7 [T/e] 3.E+13 [e/s] 3.14E+7[s] =1.E+14 [T].
Total activity of wet soil volume after one year:=
- dN_T/dt=1.E+14 / (12*3.14E+7 s) = ~2.6E+4 Bq
Or ~200 Bq/L in water (~20% by volume).

- **Tritium activity in ground water is ~3% of the VA drink water limit 7000 Bq/L .**

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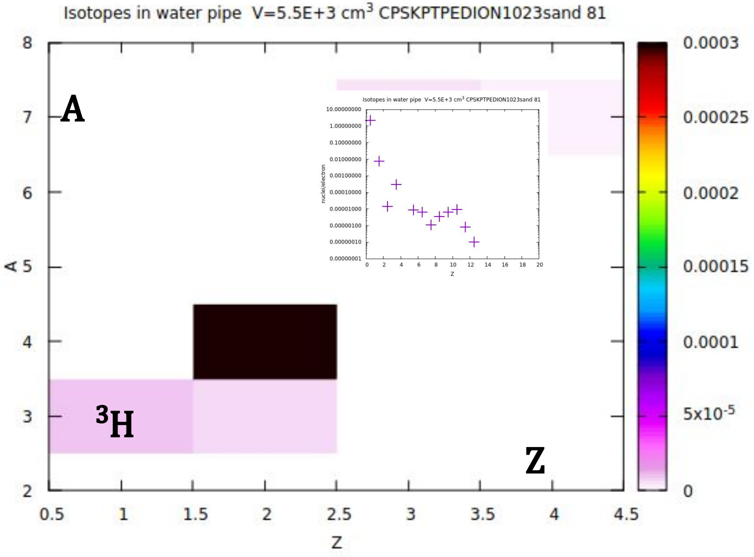
Tritium in cooling waters.



Yield of ^{3}H in the cooling water ~1.E-5 [T/e]

Number of T nuclei produced in one year: =

N_T=1.E-5 [T/e] 3.E+13 [e/s] 3.14E+7[s] =~1.E+16 [T]

Actility to be absorbed after one year:

-dN_T/dt=1.E+16 / (12*3.14E+7 s) = ~2.6 E+7 Bq

- Such activity may be diluted to 7000 Bq/L for drink water limit in 3.7 m^3 of water.

Conclusion

- CPS is an adjustable beamline Unit with photon beam channel.
- Total weight with surrounding shield ~62,000 Kg.
- CPS provides a 99% clear beam of 3.E+13 photons/s on KPT.

CPS concept allows to avoid risks of:

1. Absorber overheating (T_{max}= 200^{o} C).
2. Magnet Coil short circuit for up to 5000 days.
3. Unacceptable radiation around CPS and outside the Tagger Hall.
4. Unacceptable tritium activity in ground waters.

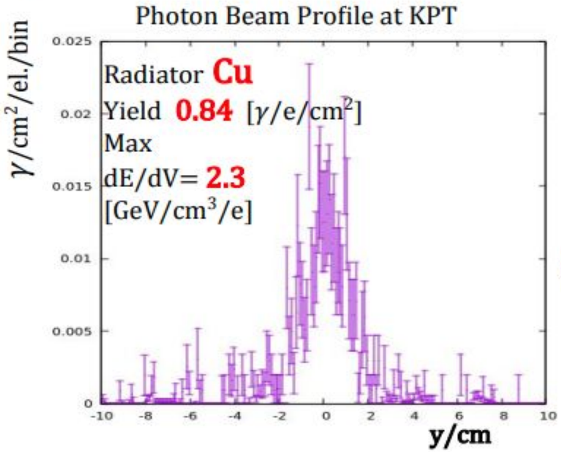
We plan

1. Further design optimization for lower weight and cost .
2. This requires iterative temperature calculations.
3. Test other design options.

The End

Effect of radiator material. Slide from CPS meeting 20-May-2022.

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

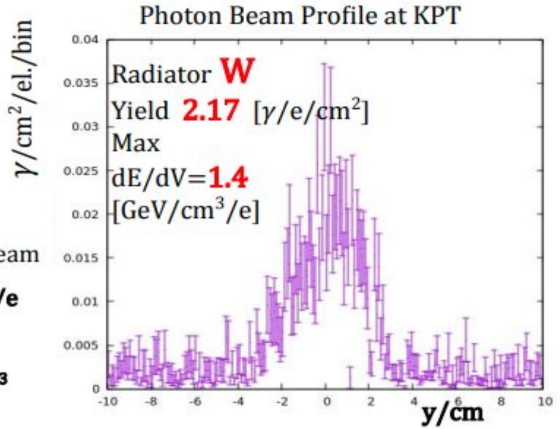


At 5μA current of e-beam

dE/dV=1. GeV/cm³/e

translates to

dP/dV = 5. kW/cm³



- **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 spot**" .
- However photon beam is **wider**. What is photon **energy spectrum**?

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- **Wider photon beam – beam quality is worse –photon conversion in very long beam pipe.**
- **Wider z-profile of energy deposition – higher radiation in coils (insulation lifetime).**