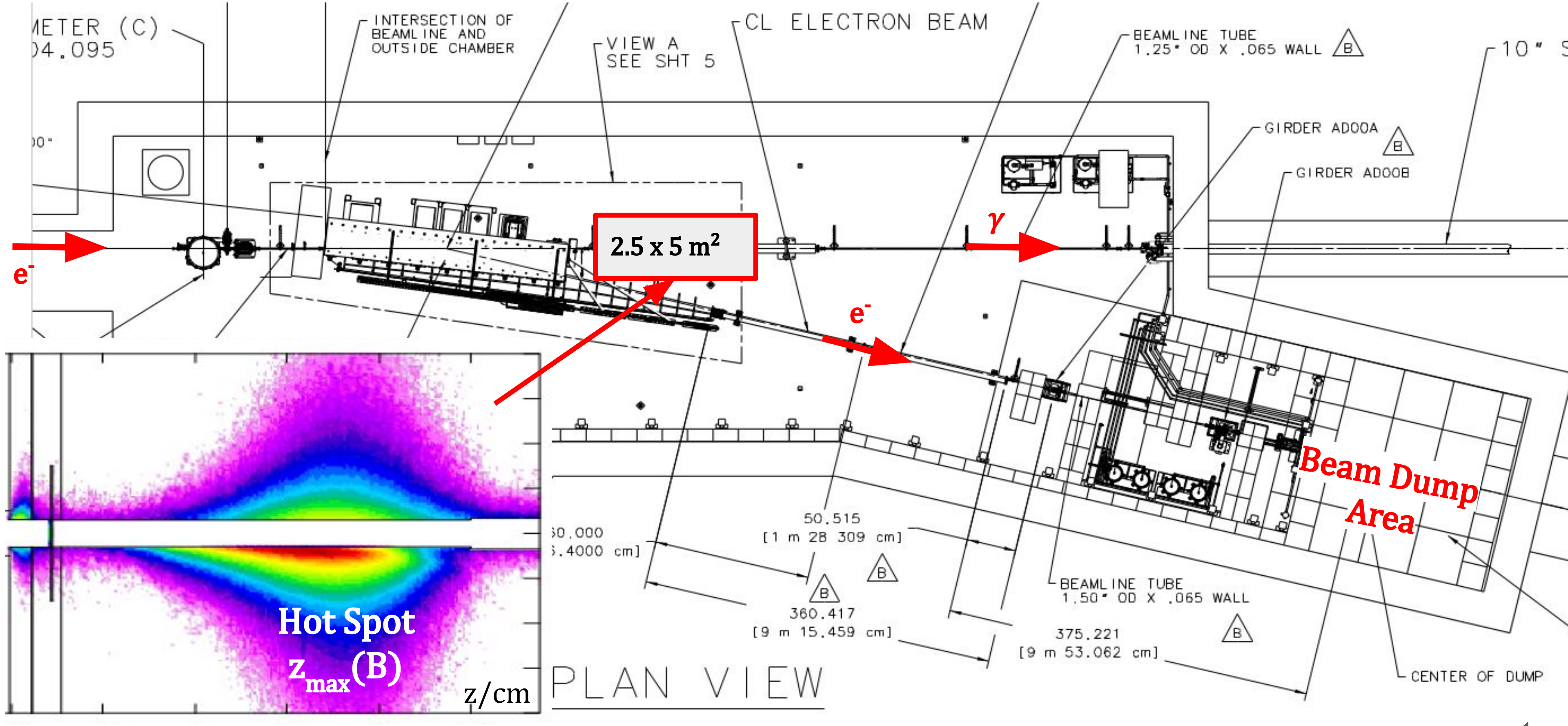
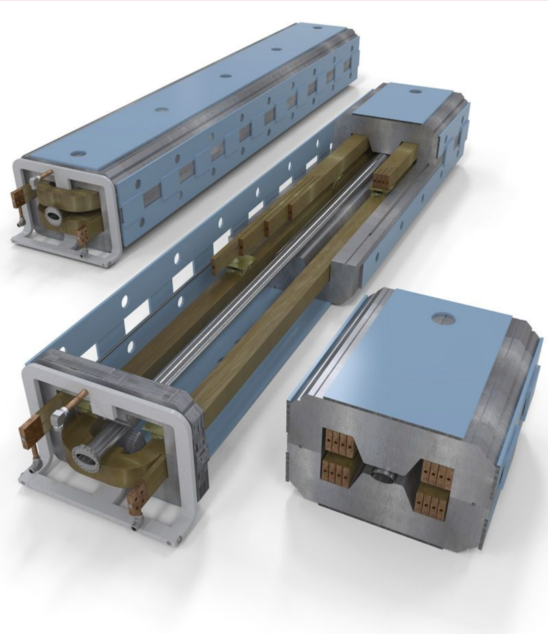
CPS with 3 m long Dipole in the Tagger Hall D.

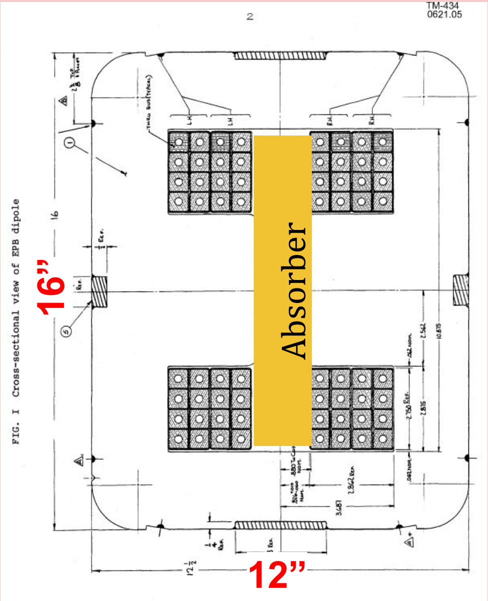


CPS 3 m Long Dipole.

FNAL prototype 1.5 T × 3 m, pole gap 4.2 cm.

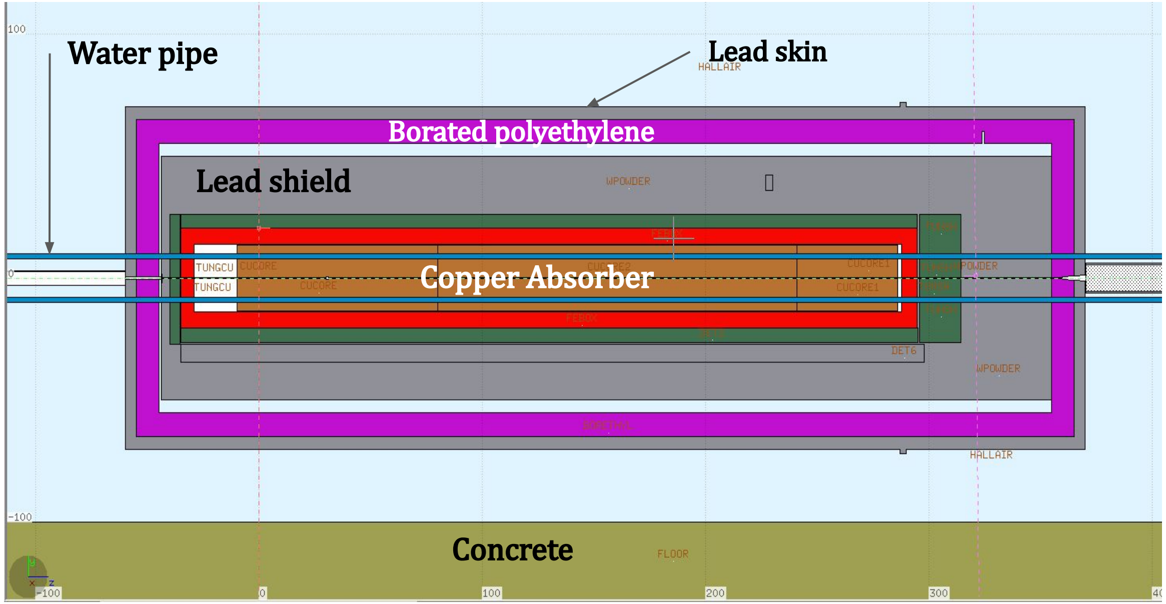


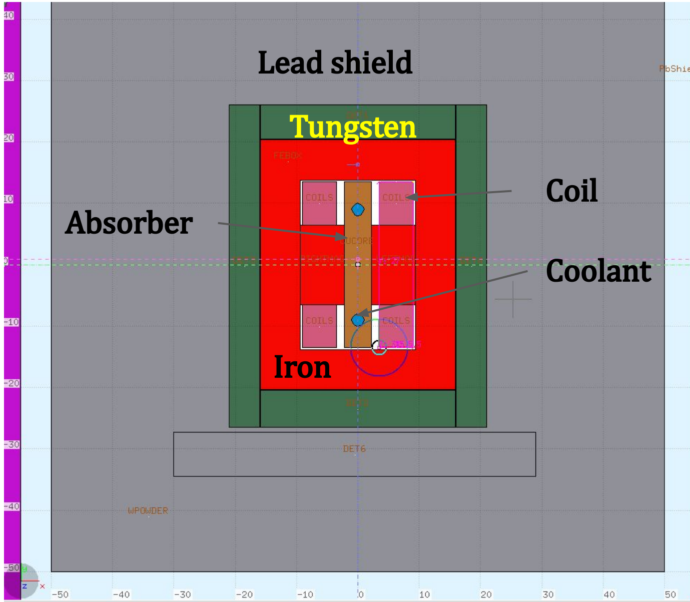
1. FLUKA model.
2. Hot Spot Size and Magnetic field.
3. Coil Insulation Lifetime.
4. Photon Beam Quality and Coil.
5. Radiological safety.
6. Absorber T° and cooling.



FLUKA model with FNAL prototype operating at B~0.1 T.

e-Beam 5 μA, FWHM = 0.25 cm, e-Beam Hole = 0.6×0.6 cm^2, Cu radiator 0.134 cm.

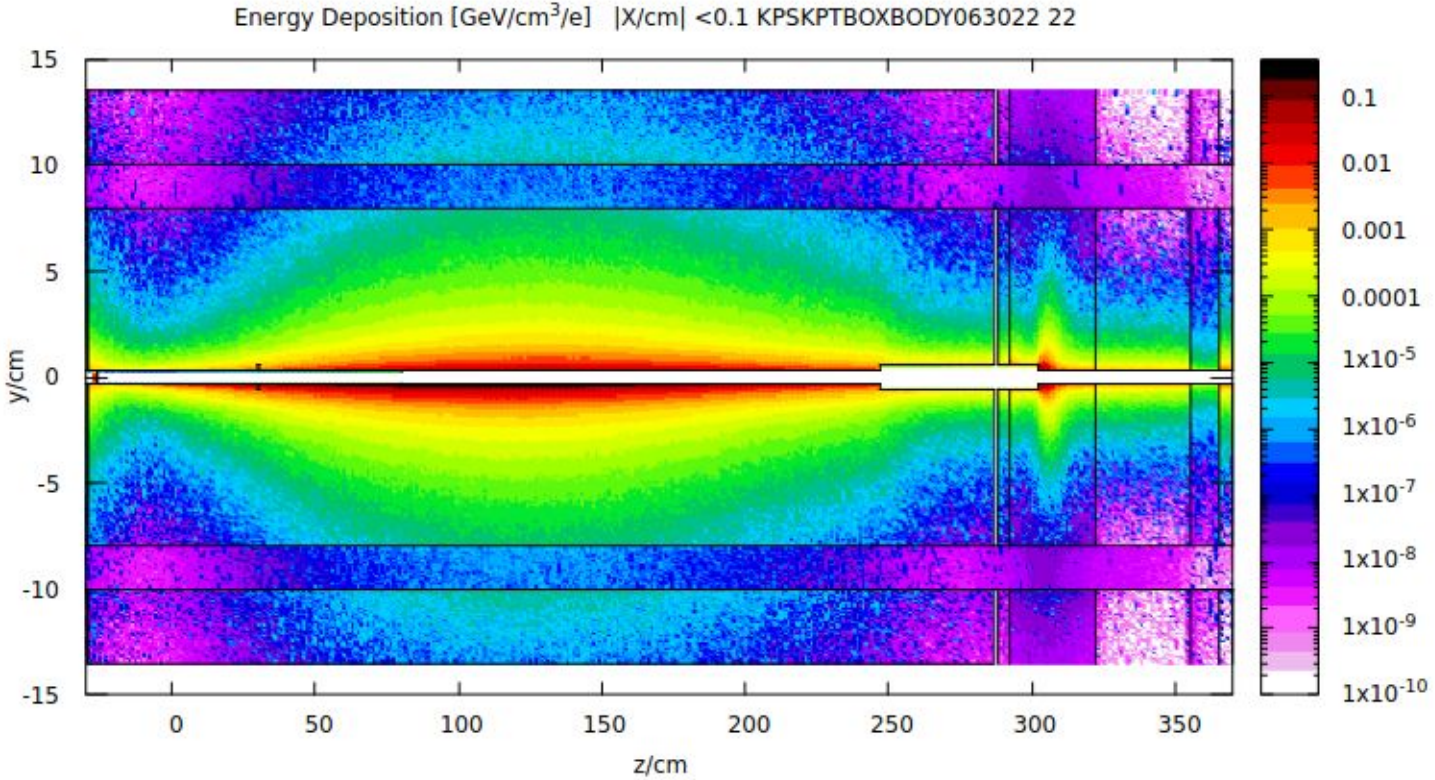




- **Absorber design** (max. T°) with autonomous cooling **determines Dipole dimensions**.
- **Low field** allows wider gap between poles => **More room** for cooling pipes.
- Magnet coil may be **0.4 m long** => more room for Absorber in Hot Spot.

Cooling pipe location and Energy Deposition in Absorber. Example at B=0.22 T.

e-Beam 5 μA, FWHM = 0.25 cm, e-Beam Hole = 0.6×0.6 cm^2, Cu radiator 0.134 cm.

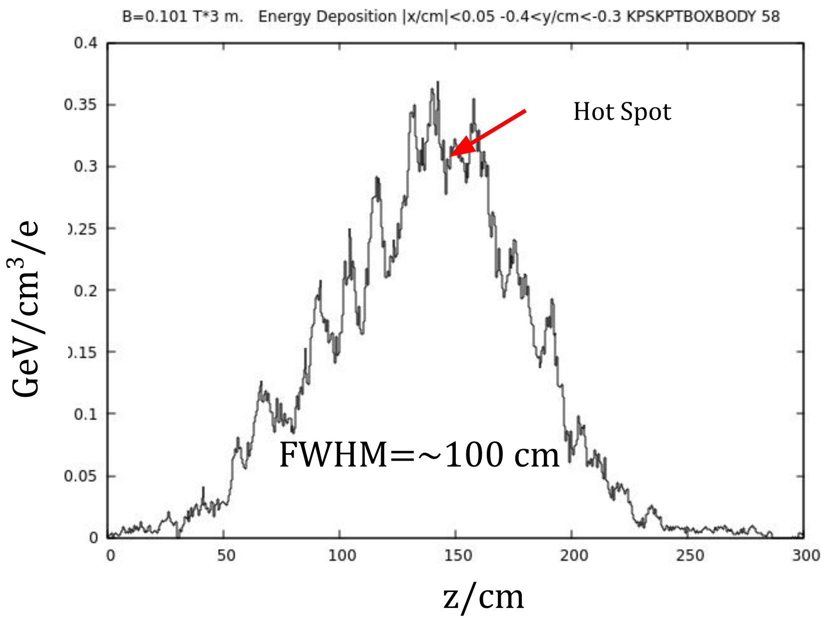


- Inside water pipes P_{max}= 2.E-6 [GeV/cm^3/e] × 3.E+13 [e/s] × 1.6 E-10 [J/Gev]=0.01 [W/cm^3].
- Total ~12 W/pipe. Looks like there is **no** problem with **water overheating**.

Power Deposition in Hot Spot vs Magnetic Field.

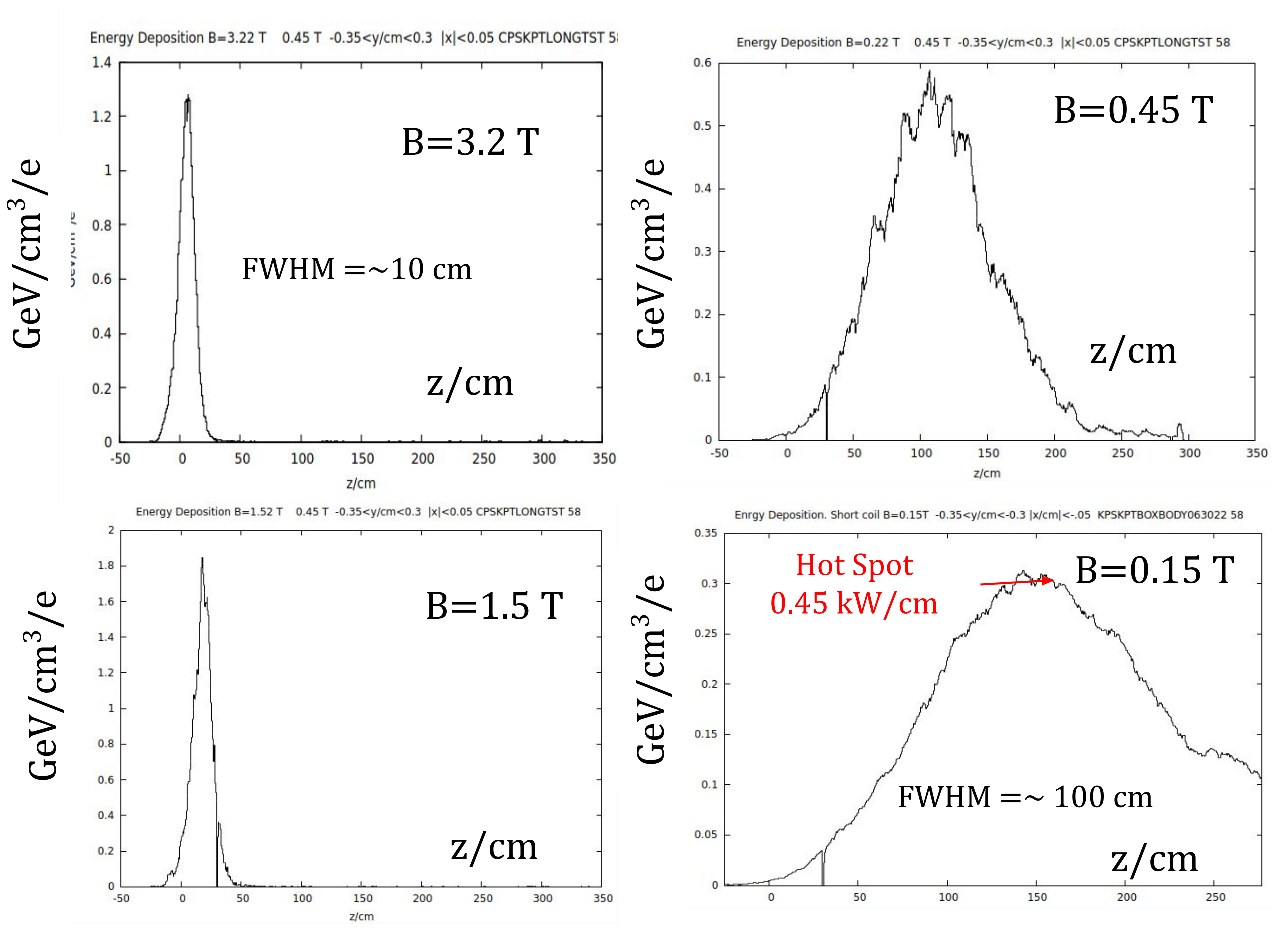
Coil 3 m long   vs Coil 0.4 m long.

Power Deposition in Hot Spot . Coil 3 m long   B=0.1 T.



- 45 kW are deposited in the Absorber.
- Maximum power deposition in the Hot Spot: dE/dzdt =45 kW/FWHM=**0.45 kW/cm.**
- This value determines the **Hot Spot Temperature**.

CPS with 0.4 m coils. Energy deposition profile vs Magnetic Field.



- If 45 kW are deposited in the Absorber, the maximum power deposition

dE/dzdt =45 kW/FWHM=

0.45 kW/cm.

- Hot Spot T^o $\propto$ max dE/dzdt.

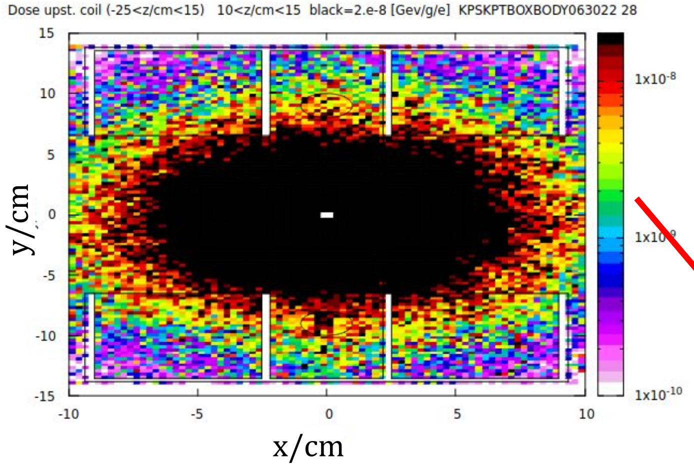
Lifetime of Coil Insulation

vs

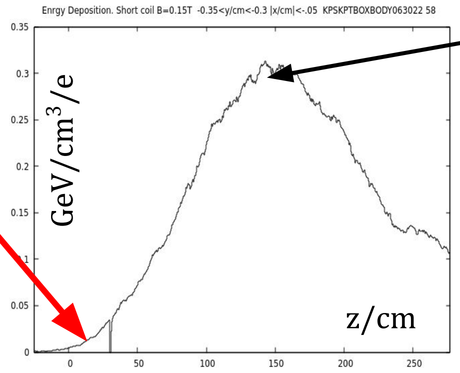
Coil Design.

Short coil vs Long coil. Prompt Dose and Insulation Lifetime.

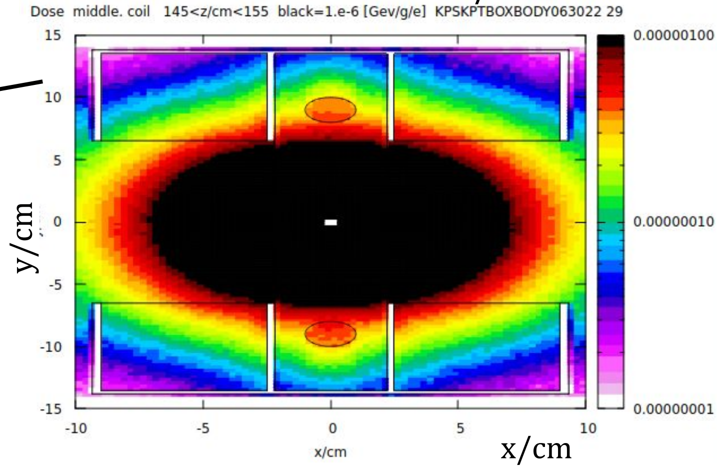
Dose in 40 cm coil at 10<z/cm<15



Energy Dep. z-profile



Dose in 3m coil at 145<z/cm<155

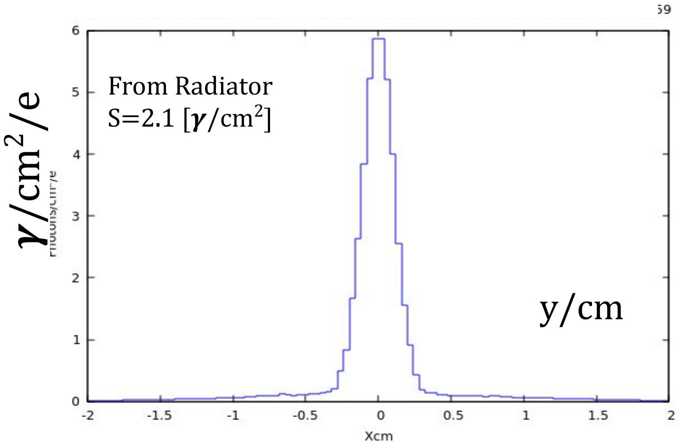


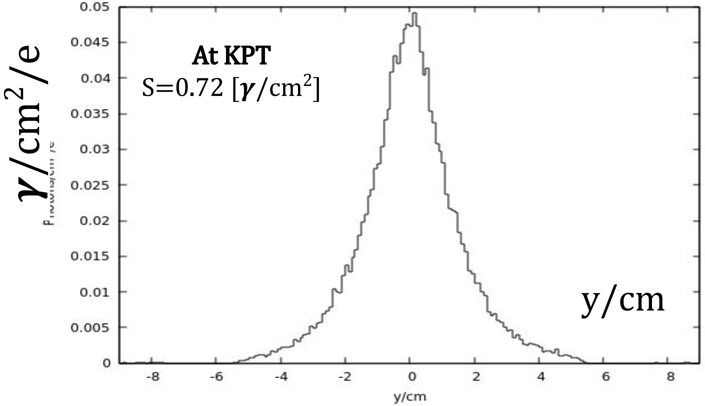
- **Short 40 cm coil** is wind within -25<z/cm<15 ; Long **3m coil** – within -28.5<z/cm<287.
- The maximum **dose in the 40 cm coil** ~**2.E-8 [GeV/g/e]** or **3.2E-15 [Gy/e]** (×1.6E-7 Gy/(GeV/g)).
- At 5 μA we have 3.E+13 [e/s] => in 40 cm coil dose rate = 3.2E-15 [Gy/e]×3.E+13 [e/s] ≅ **0.1 [Gy/s].**
- **Kapton withstands 1.E+7 [Gy]** => **Lifetime** ~1.E+8 [s]=**1160 days of continuous operation.**
- In **3m coil** the maximum dose ~**0.6E-6 [GeV/g/e]**, and **Lifetime** = **40 days** .
- Lifetime may be **5 times longer** using **fiberglass cloth**.

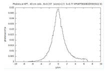
Photon beam quality.
Short Coil vs Long Coil.

Photon Beam profile at KPT. Long vs Short coil.

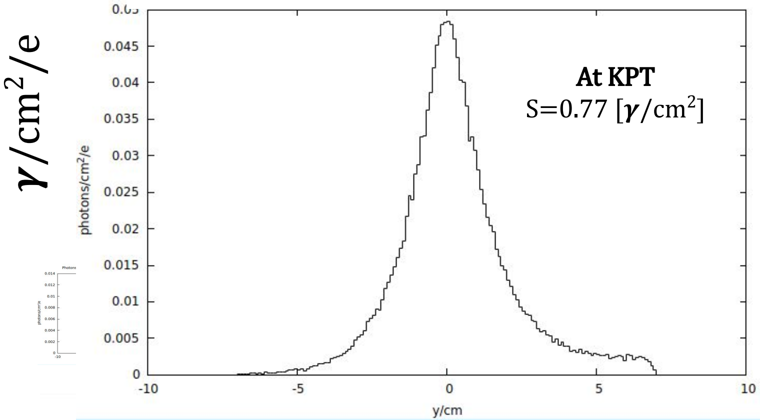
Coill 3 m B=0.1 T

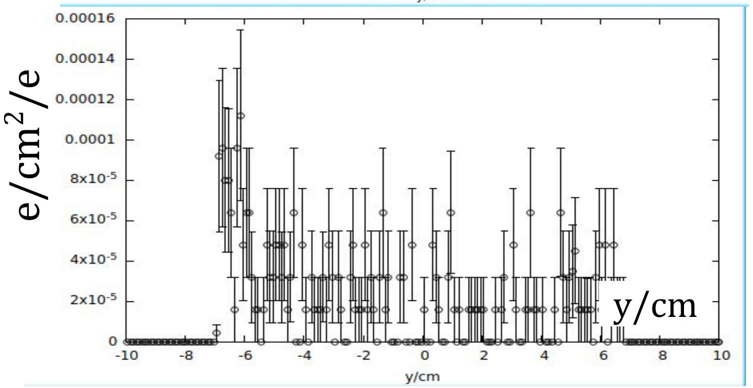


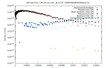




Coill 0.4 m B=0.18 T



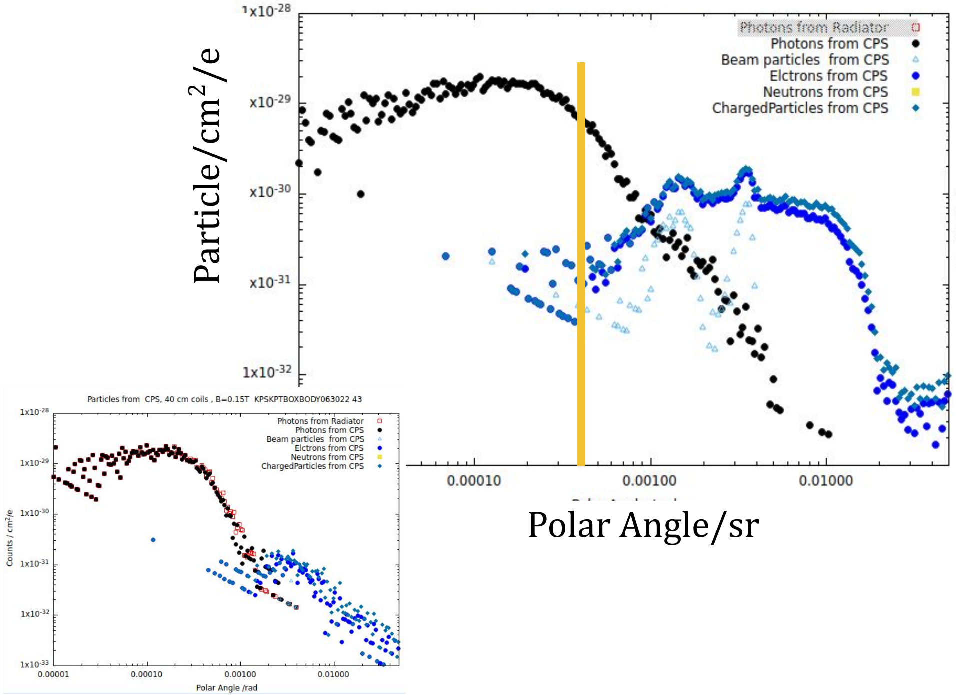




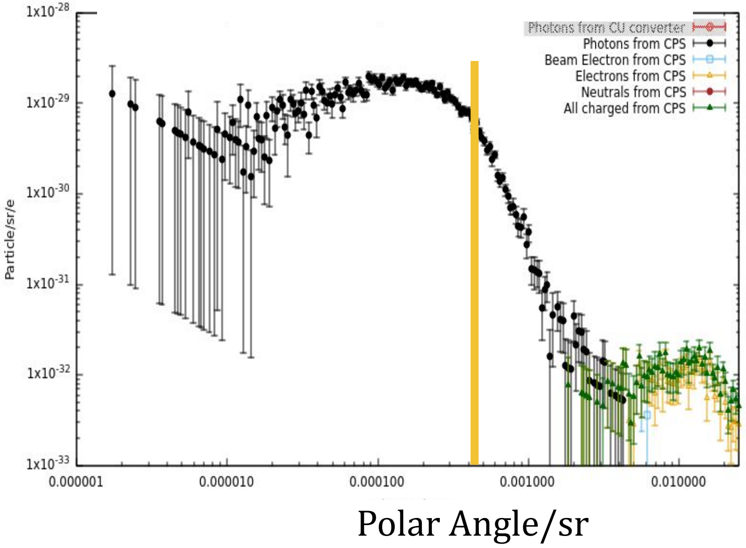
- Photon beam profile fits well the Be target of KPT, but there is ~1% background of electrons.

Photon Beam quality at CPS exit. Coil 0.4 m vs 3 m long.

Coill 0.4 m B=0.18 T



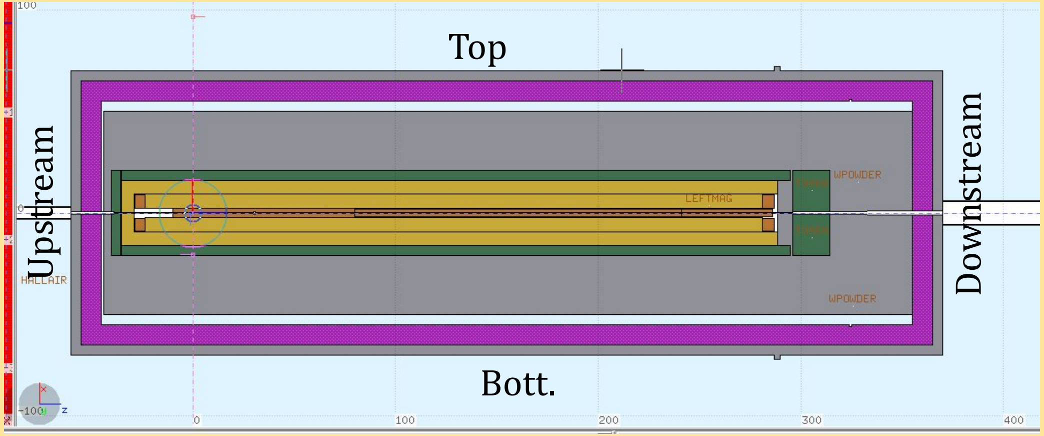
Coil 3 m B=0.1 T



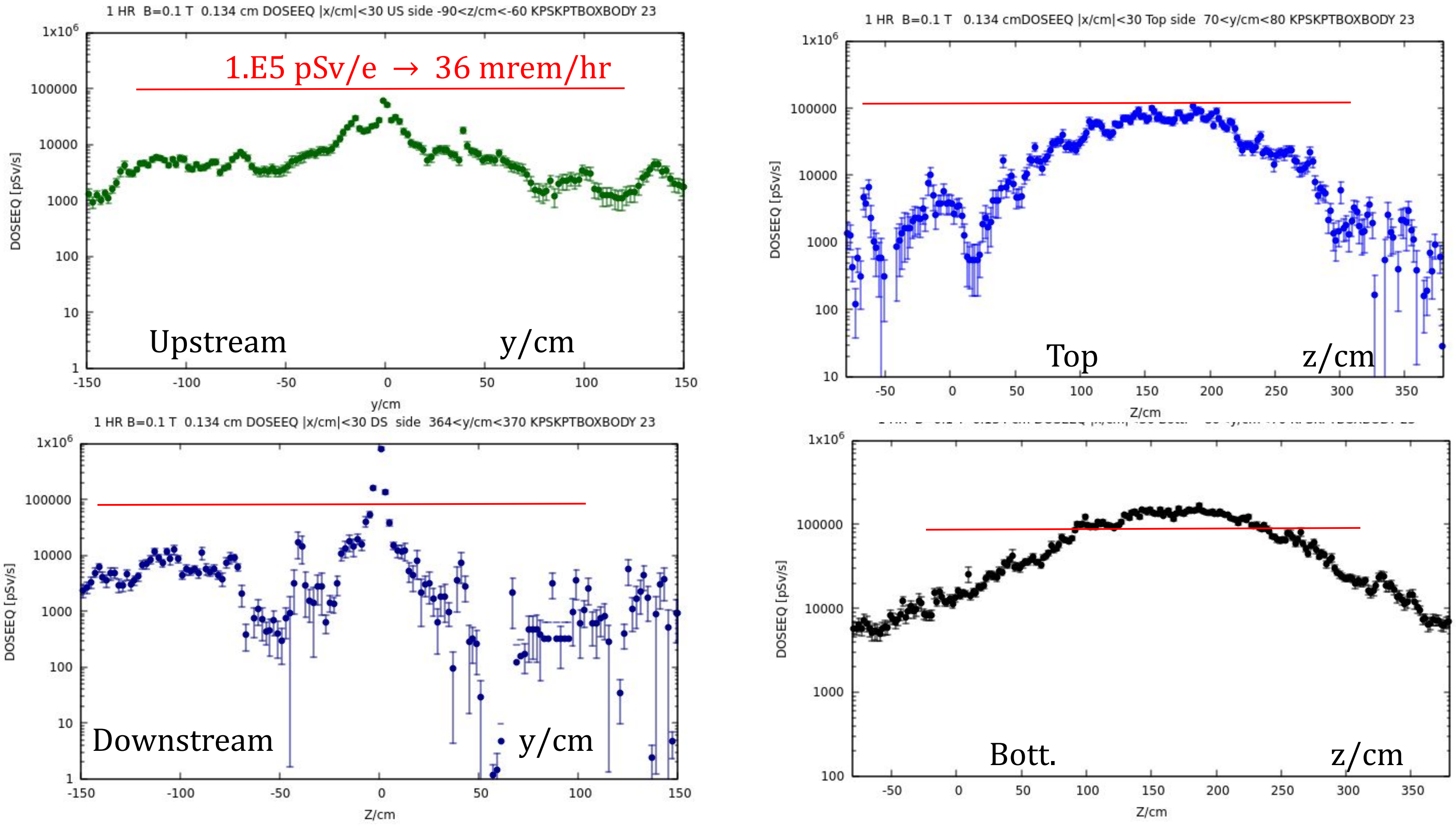
- Background   is below 1% in the KPT acceptance of 0.4E-3 sr.
- May be cleaned up by the beam line **permanent magnet downstream** the CPS.

Radiological safety.

Dose Equivalent rates after 1000 hrs of continuous operation and 1 hr break at 4 surfaces of CPS

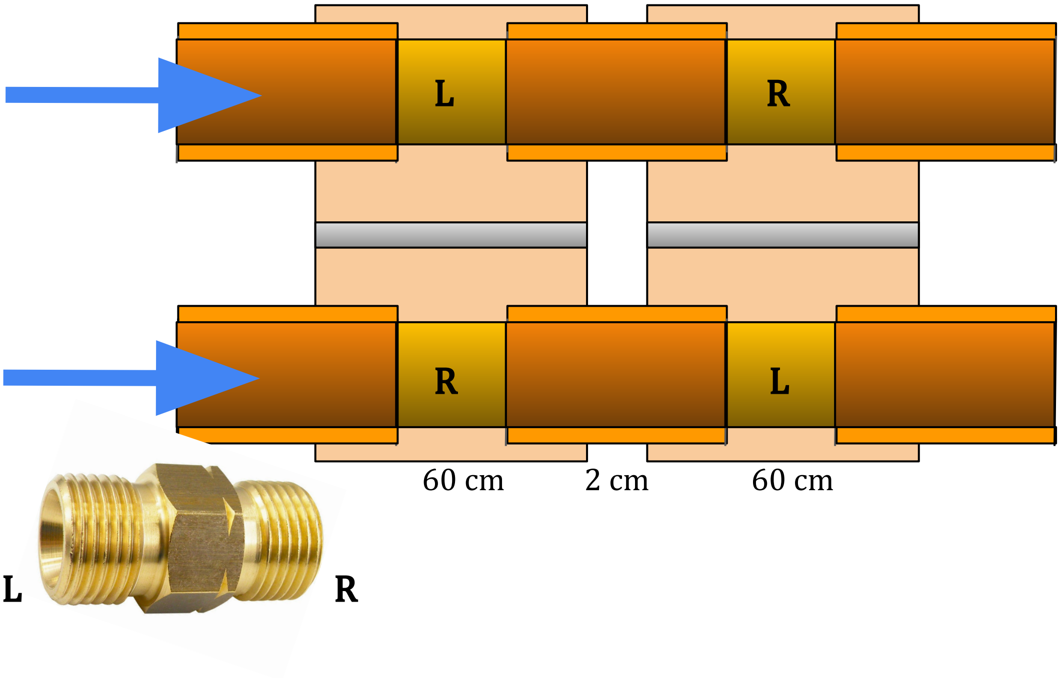


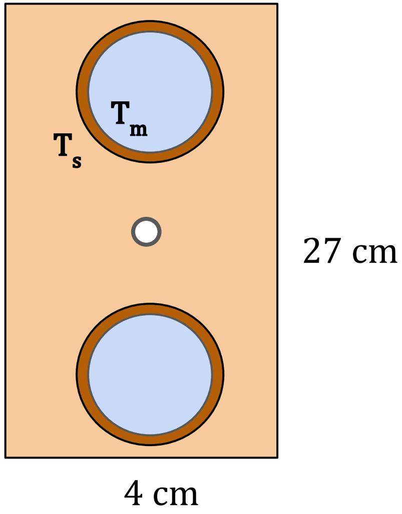
After One Hr Dose Equivalent is below 100 mrem/hr . Dipole 3 m × 0.1 T.



Absorber Design and Cooling

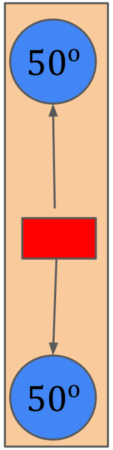
Segmented Copper Absorber inside Dipole 0.1 T ✕ 3 m.





- Absorber with **round** beam **hole** eliminates the problem of top–bottom thermal contact.
- **Direct contact to cooling liquid** in each segment is an advantage.

Cooling and Temperature jump at the Absorber-Water boundary.



Copper Bar
l=100 cm
w=4 cm
h=27 cm.

- What should be the temperature difference between Absorber and Coolant ?
- For heat transfer rate from the surface at T_s to liquid at T_m via area A we write:

$$dQ/dt=k\,(T_s - T_m)\,A \;=\; 45\text{ kW},$$

where area $A= \boldsymbol{\pi}\, wl =1250\text{ cm}^2$,

k=4.E-2 [W cm^{-2} K^{-1}] – "**heat transfer coefficient for laminar flow**";

tabulated empirical value for "water-Cu-water" contact; to be doubled for "Cu-water" contact.

May be 2-3 times higher for **turbulent** flow. Is it **used in FEA calculations (?).**

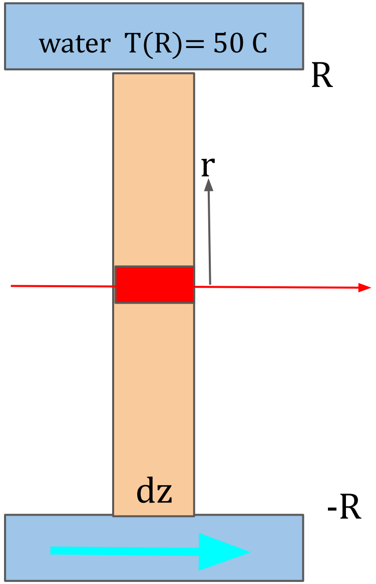
To sink the uniformly distributed 45 kW power from $4\times27\times100\text{ cm}^3$ bar, we find:

$$T_s - T_m = 45\text{ kW}/(8.\text{E-2 [W}cm^{-2}K^{-1}]\ 1.25\ \text{E+3 [cm}^2]) = 450\text{ K.}$$

- **At** T_m= 50 C **Absorber temperature at contact with water** yields: $\mathbf{T_s = 500\ C}$ **.**

- To reduce $\mathbf{T_s}$ make Absorber width proportional to dE/dzdt.
- How **heat transfer coefficient** is addressed in **Fluence FEA software**?

Absorber slice heating by 0.45 kW/cm in Hot Spot.



Copper Bar
$dz \times a \times 2R\ cm^3$

- Energy deposition rate in the Absorber dz-slice along beam line :

  $dE/dt = dz \times \mathbf{dE/dzdt} = dz \times \mathbf{0.45\ kW/cm}$;

- Energy balance in case of steady heat flow : $dz\,(dE/dzdt) = dz\,(-\,2\,a\,\varkappa\,dT/dr)$,

  => $dE/dzdt = -\,2a\varkappa\, dT/dr$,

  $dT = -(2a\varkappa)^{-1}\, dE/dzdt\ dr$, integrate $\mathbf{r < R}$,

  $T(r) - T(R) = (2a\varkappa)^{-1}\, \mathbf{dE/dzdt}\ (R-r)$,

  where

dE/dzdt =0.45 [kW/cm] ; from previous slide.

T(R)=500 C ; estimate of Absorber temperature from the previous slide

Absorber height = 2R; R=8 cm; Absorber width a=3.7 cm

Heat conductivity for Copper $\varkappa$ = 3.98 W/cm•K ; for Tungsten = 1.73 W/cm•K.

$T(0)-T(R) = (2 \cdot 3.7 \cdot 3.98)^{-1}$ [K/W]*0.45E+3 [W/cm]* 8 [cm]= **120 K. (~300 K for tungsten)**

Maximal Hot Spot Temperature yields: T(0)=500 C + 120 K = 620 C .

- **Looks like we may avoid melting of copper.**
- **FEA calculation of the Absorber cooling are required ASAP using Fluence software.**

Is it possible to evacuate 60 kW from the Absorber?

- Water speed required to evacuate dE/dt=60 kW through 3 cm-pipe L=3 m, $S=7\ cm^2$

  $dE/dt=C_v(T_{out}-T_{in})\ v\ S$, (1)

  where

  $C_v = 4.2\ [JK^{-1}cm^{-3}]$ – specific heat capacity of water

  $T_{out}-T_{in} = 70\ C$ – water flow temperature change.

With these numbers Eq. (1) yields:

  $6.E+4W = 4.2\ [J\ K^{-1}cm^{-3}]\ 70\ [K]\ 7\ [cm^2]\ v\ [cm/s]$,

  and we find **v = 30 [cm/s].**

- Heating time is of 10 s that is enough to reach $T_{out}=90\ C$.
- Water flow speed looks consistent with the power deposition of 60 kW.
- Absorber design looks practical and may be optimized using FEA of heat flow.

Conclusive remarks

- With **~0.4 m long coils and lower field ~0.1 T** we avoid the **risk of Absorber overheating**.
- With ~**0.4 m coils and lower field** we avoid the **risk of coil short circuit** ,for up to 5000 days.
- **After 1 hr Dose rates** at CPS surfaces are far **below 100 mrem/hr** (High Radiation Area).
- **Photon beam** may additionally **cleaned up** with the Hall D beam line magnet.
- Total **CPS weight** is of 60 metric tons.
- Long magnet yoke (3 m) is a stable and adjustable housing for Absorber.

<u>What we need to proceed with Dipole design.</u>

- Thermal **FEA** model (Fluence software) of Absorber and **cooling lines** with known *heat transfer coefficients.*
- **Mesh for** thermal **calculations** should scale in fraction of ***mm*** in the hot spot.
- Iterative **Temperature field** calculation using **Energy Deposition** Map from FLUKA to **optimize Dipole** dimensions.