Meeting 06/20/23

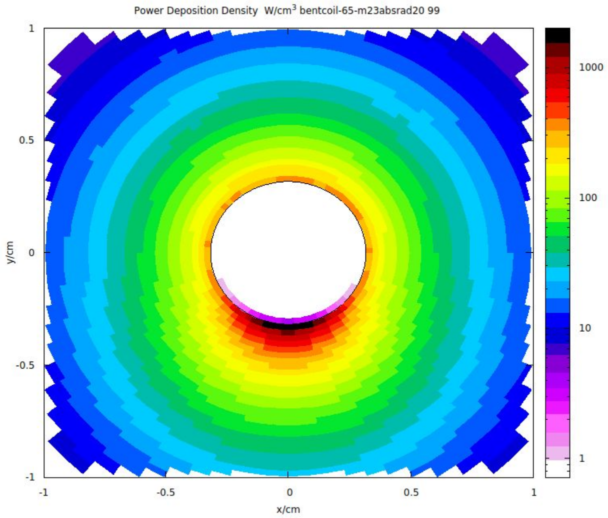
Homework from Meeting 06/12/23

1. PDE +Activation around CPS with 2.5 mm beam sigma.
2. Simulations of CPS with 3.5 mm beam sigma.
3. CPS material budget/cost.
4. CPS optimisation.

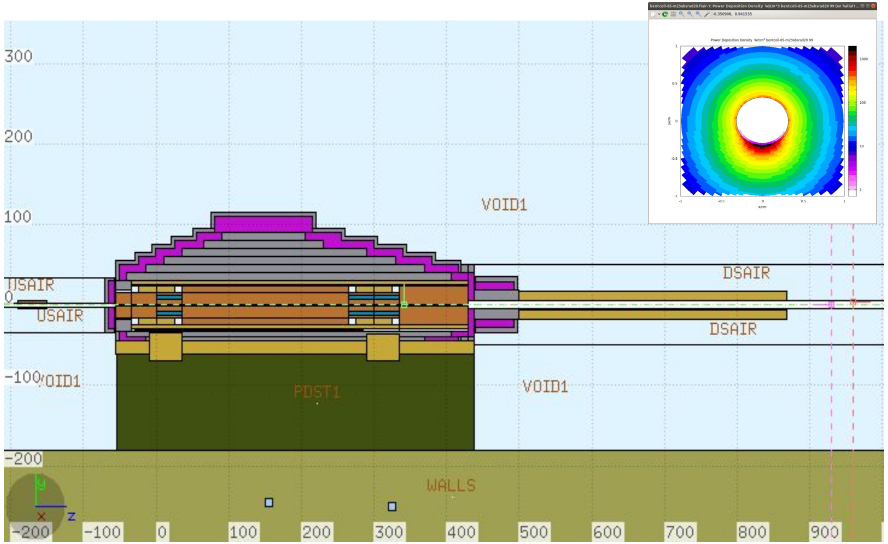
Next week calculations (request from Hovanes)

1. Simulations of CPS with 1.5 mm beam sigma (background, magnet).
2. Simulations with 1 mm horizontal shift (background, temperature).

Beam 2.5 mm.
PDE and Activation.



Prompt Dose Equivalent Map (rem/hr) < 500 ; beam 2.5 mm; $B=0.9B_n$



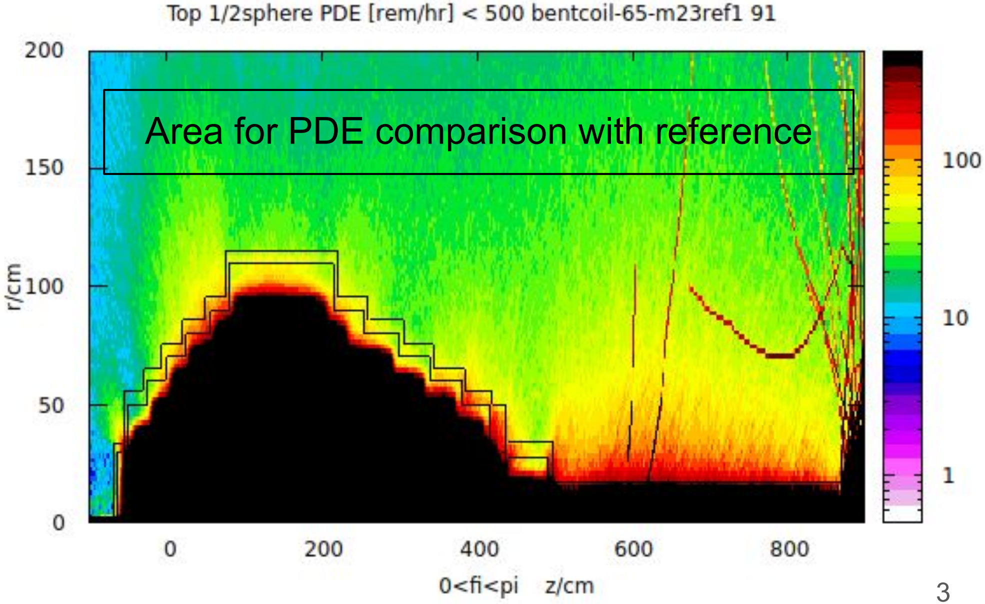
Modified shielding. Not yet optimized.

Max Radius changed from 86 to 110 cm.

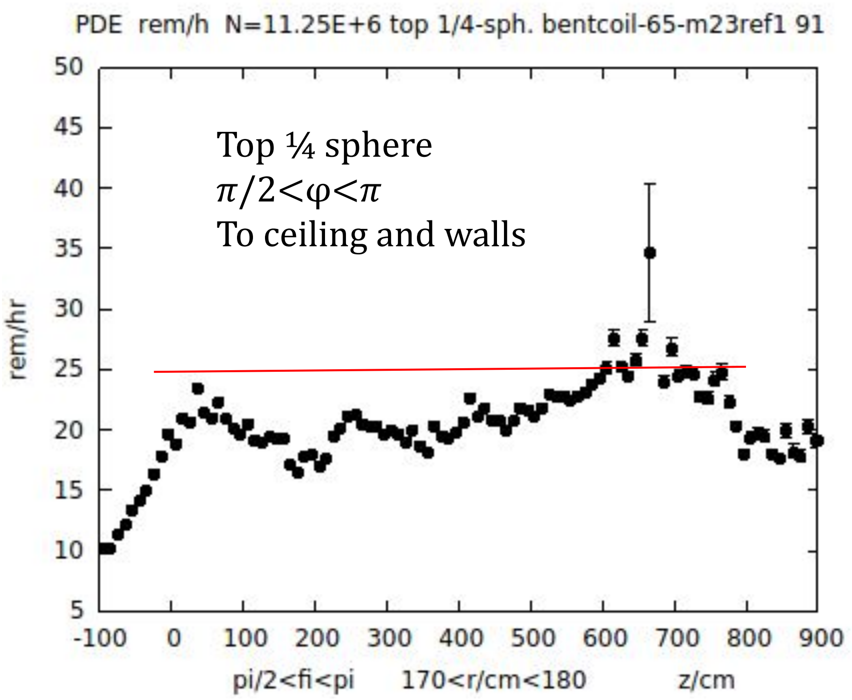
May be not necessary.

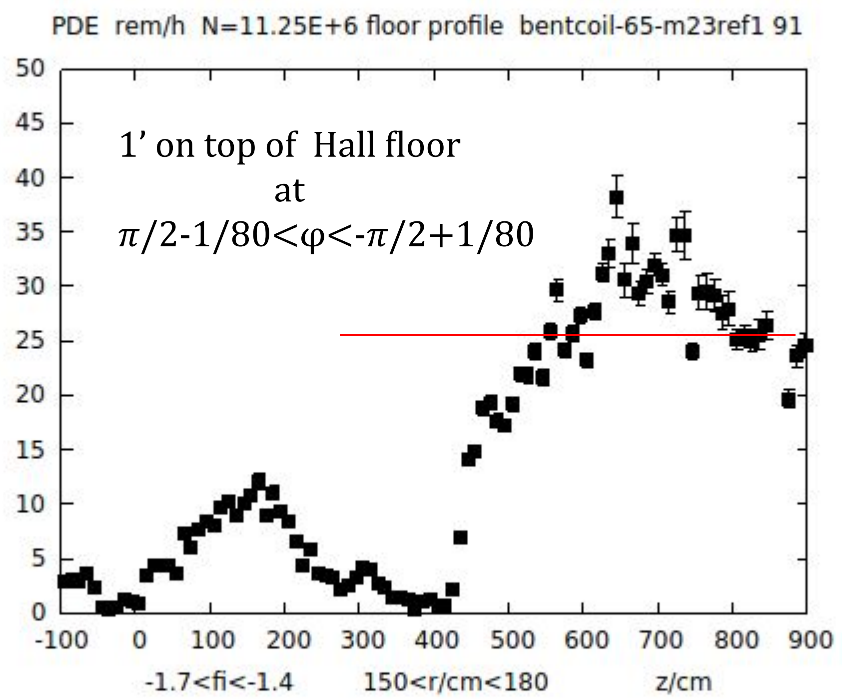
PDE r vs z map in rem/hr

z- profiles at the next slide.



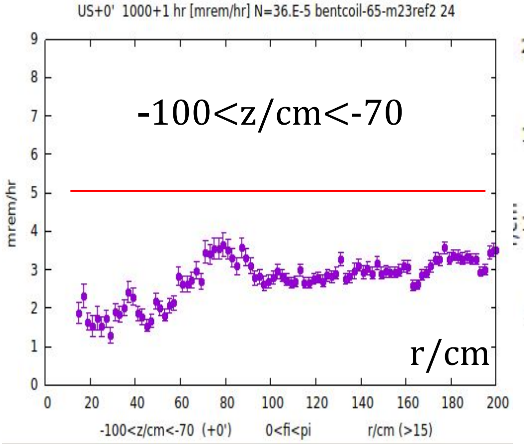
Prompt Dose Equivalent (rem/hr) at r=150-180 cm from beam 2.5 mm.

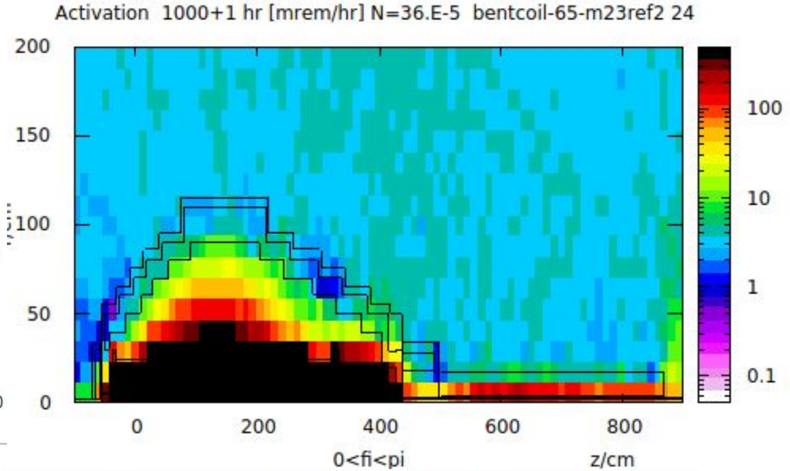


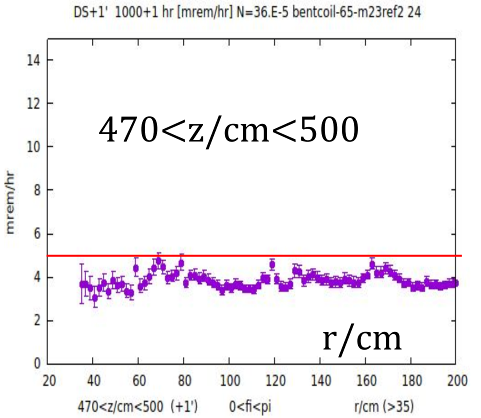


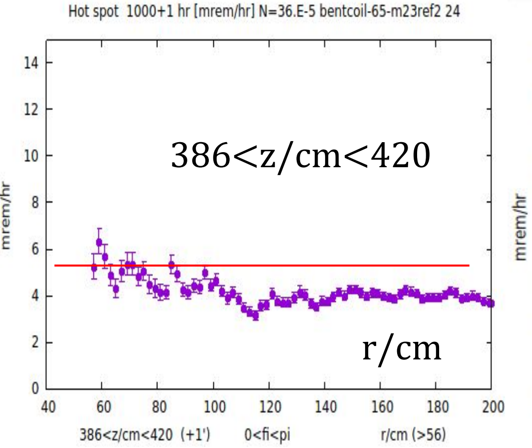
- At beam 2.5 mm PDE **meets the specification of the PAC48 proposal**: PDE<25 rem/h at floor level 1.5-1.8 m.

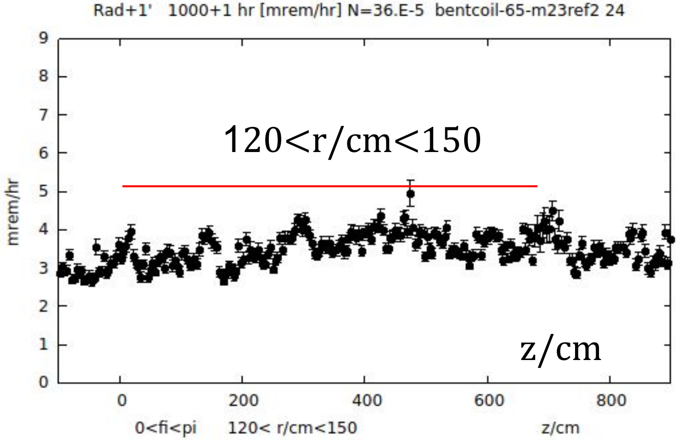
Activation 1000+1 hr is **below 5 mrem/hr**. $B=0.9B_n$. Beam 2.5 mm.

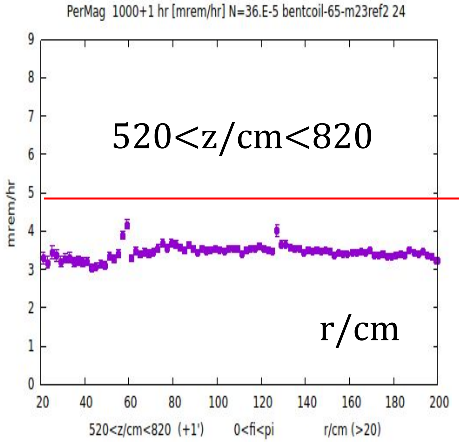




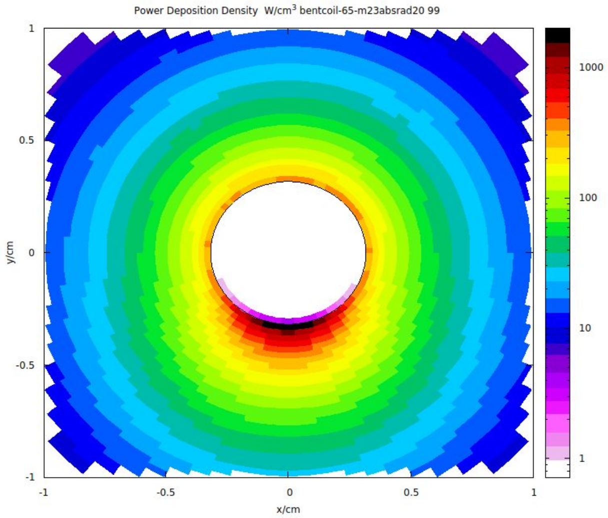




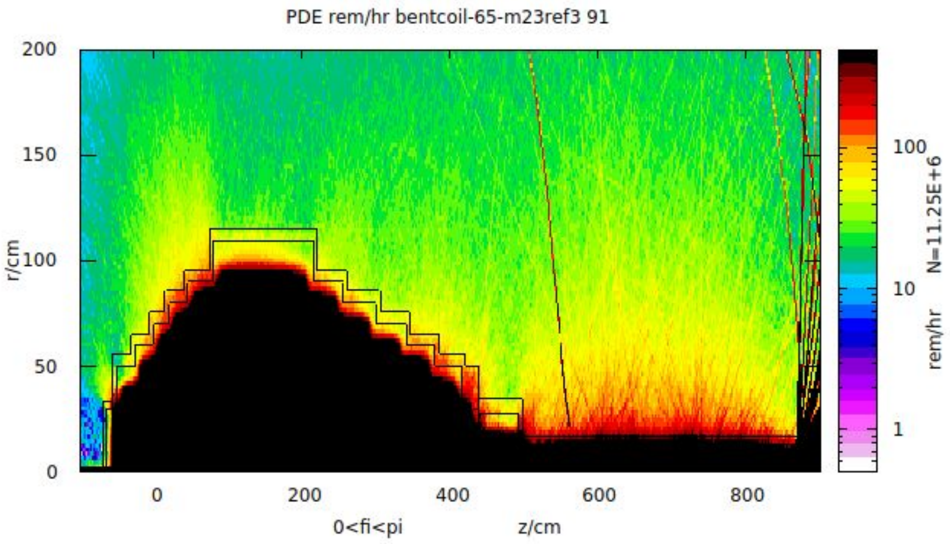


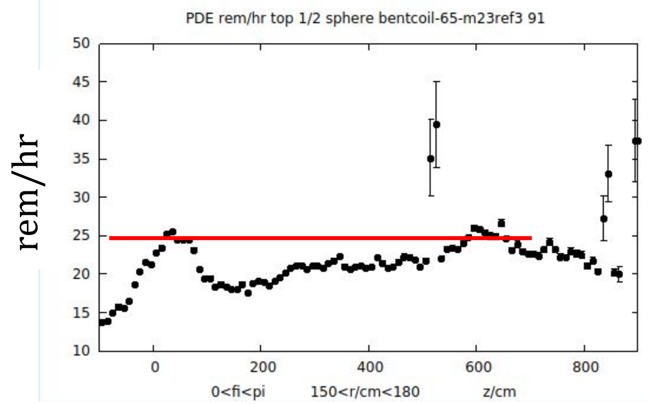


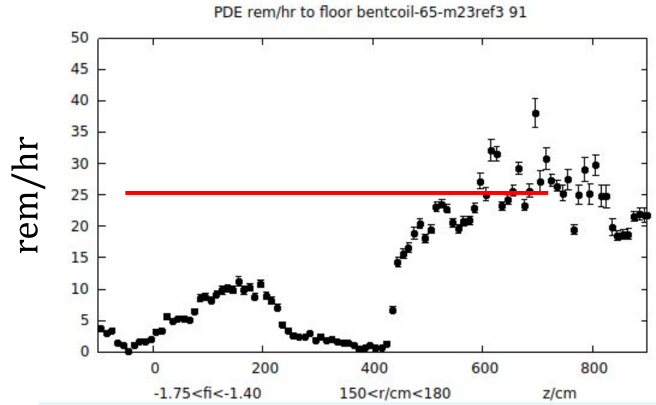
Beam 3.5 mm.
PDE and Activation.



$B=0.9B_{n.}$ Prompt DE<25 rem/h at r=150-180 cm from Beam 3.5 mm.

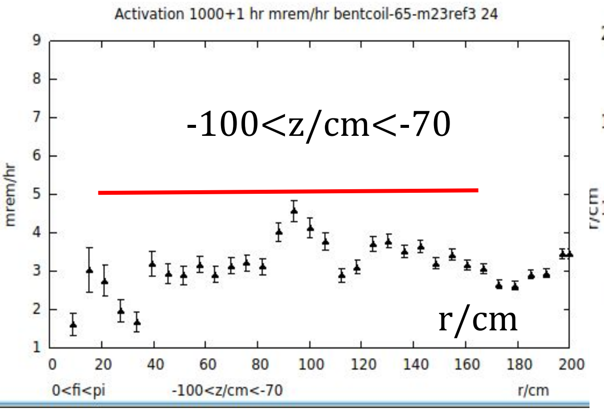


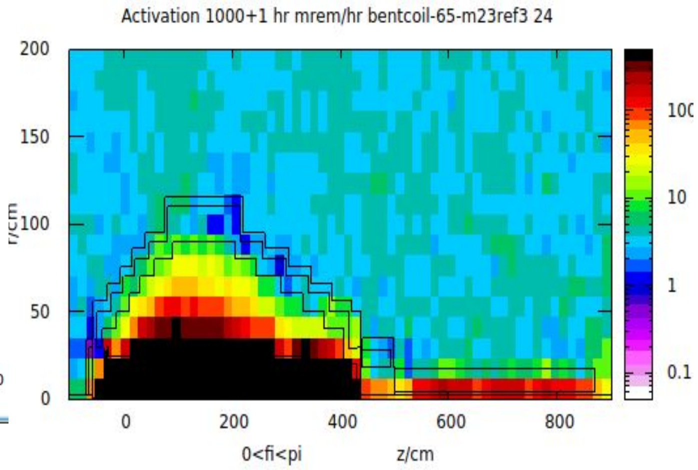


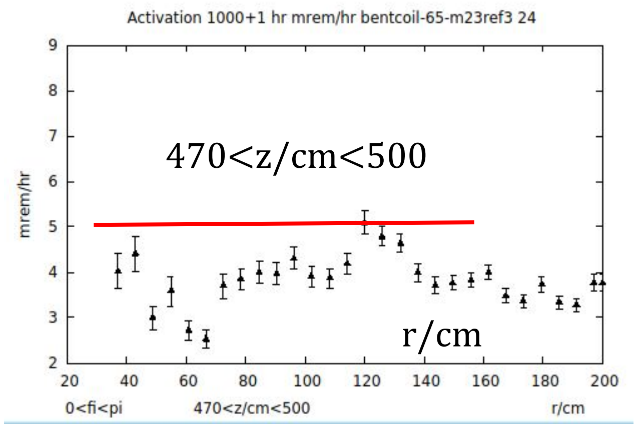


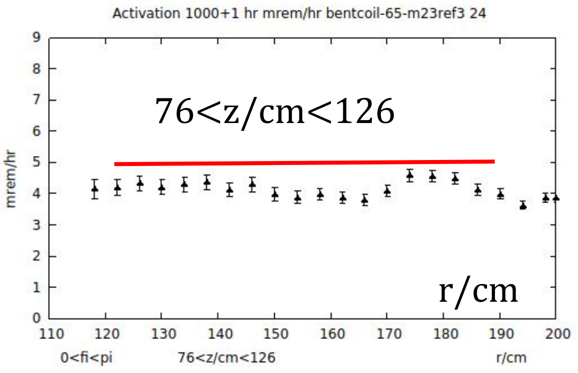
- At beam 3.5 mm PDE **meets the specification of the PAC48 proposal**: PDE<25 rem/h at floor level 1.5-1.8 m.

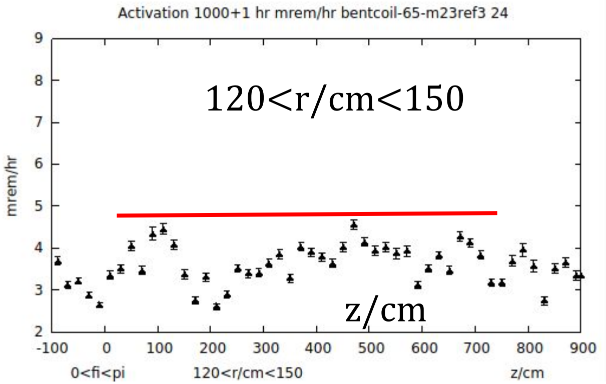
Beam σ=3.5 mm. B=0.9B_n. **Activation** 1000+1 hr is **below 5 mrem/hr.**



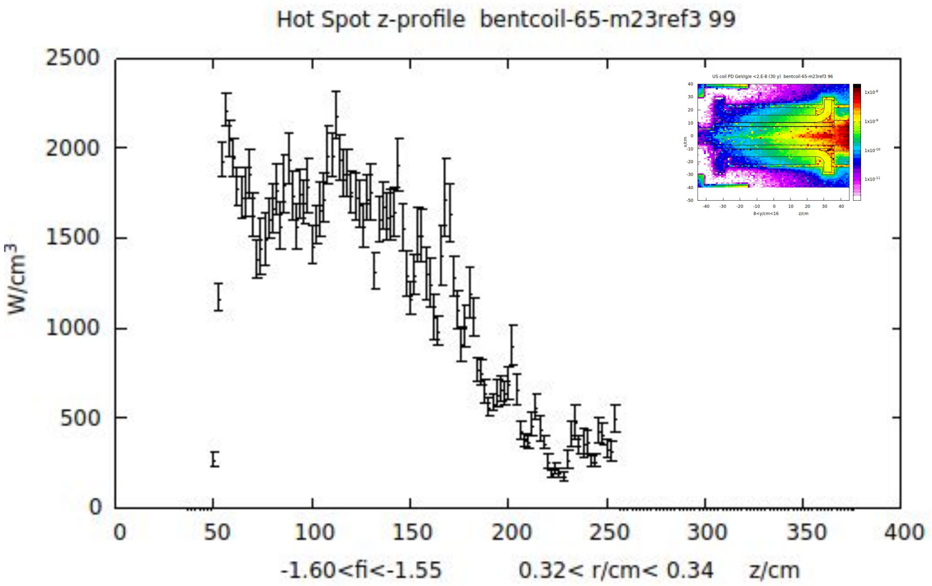


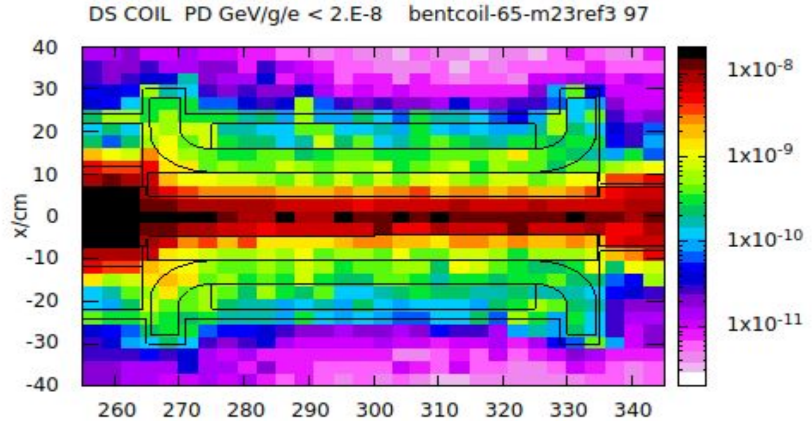


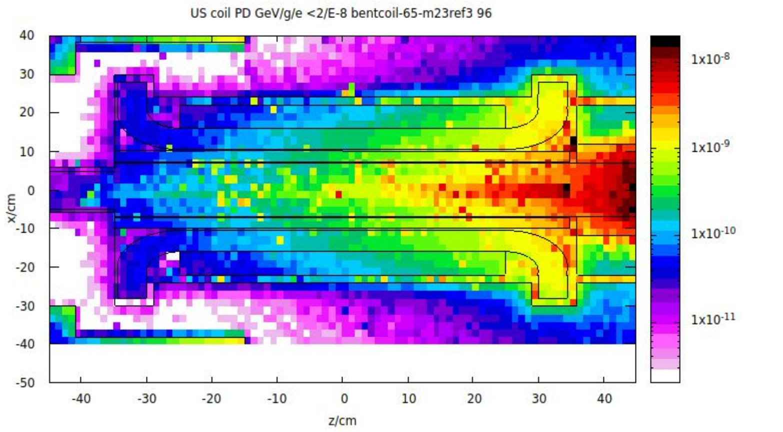




Max. dP/dV and Coil Lifetime. Beam 3.5 mm. B=0.9 B_n.







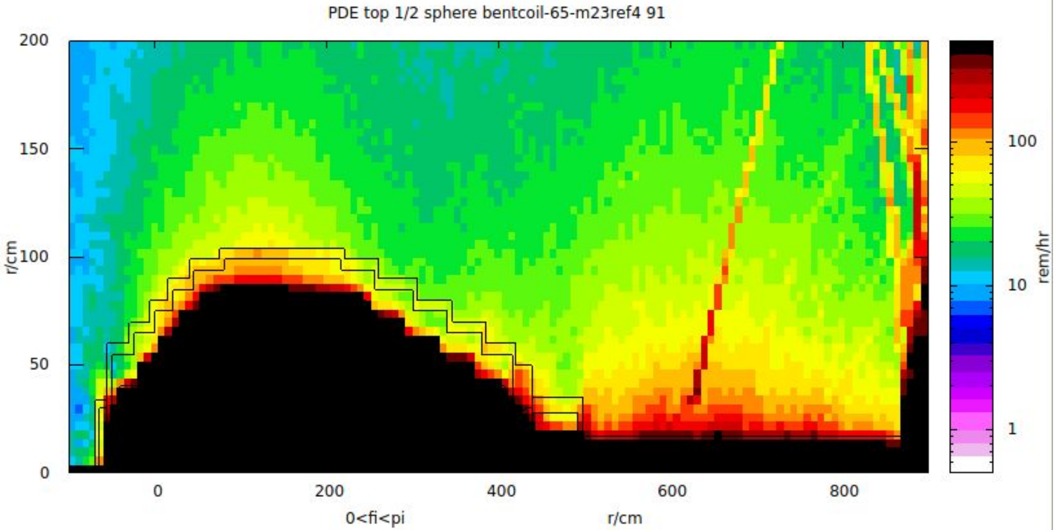
- Maximal dP/dV - **2.1 kW/cm^3**
- In Coil the **PD<2.E-9 GeV/g/e** => **Coil LT~300 years** of continuous operation.

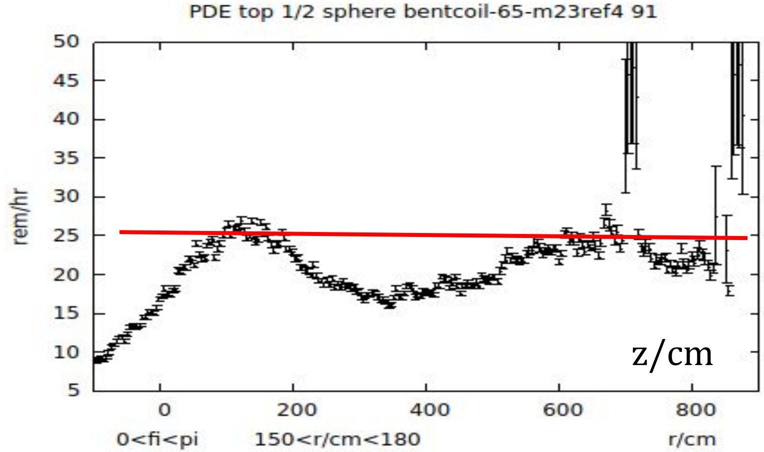
Beam 3.5 mm.

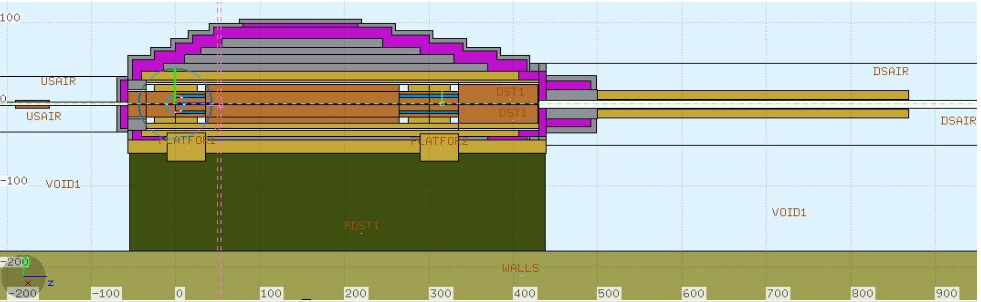
PDE and Activation.

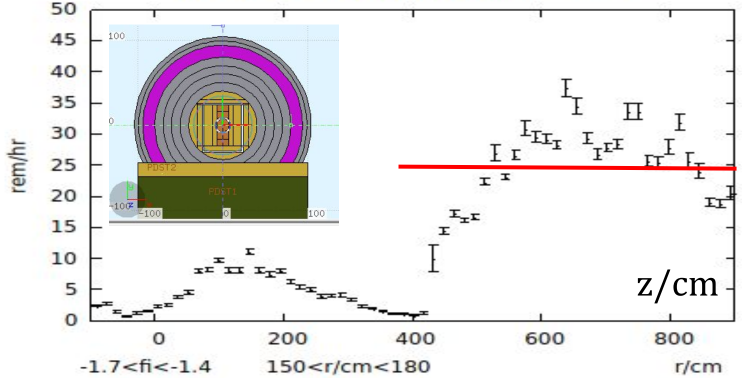
Shield optimization.

PDE (rem/hr) at r=150-180 cm from beam 3.5 mm. $B=0.9B_n$. Iron core.



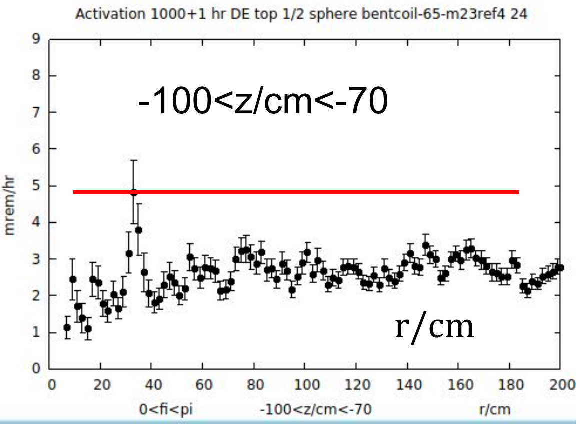


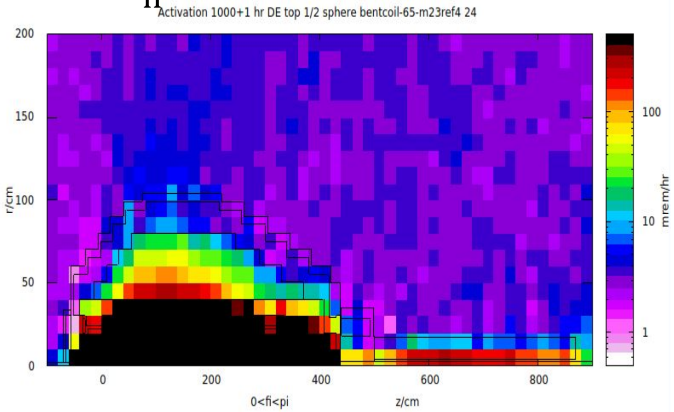


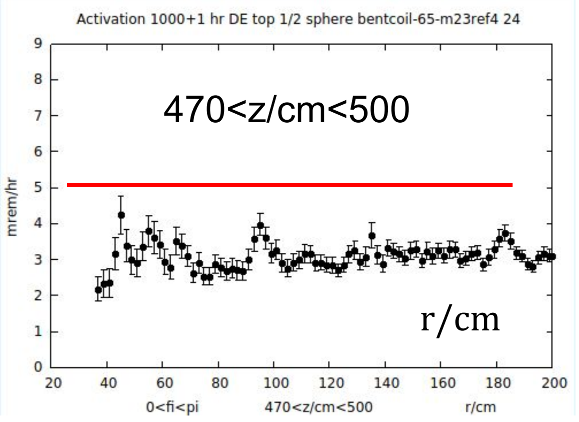


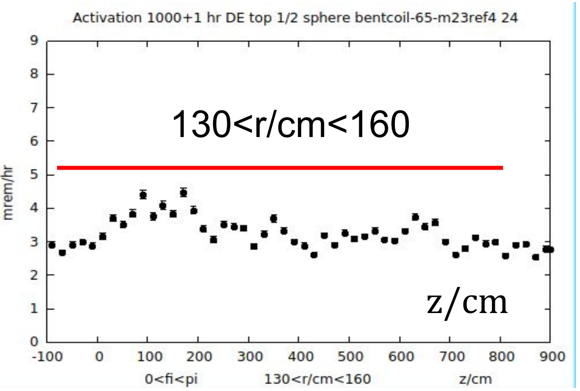
- With iron core, beam 3.5 mm, PDE **meets the specification of PAC48.**

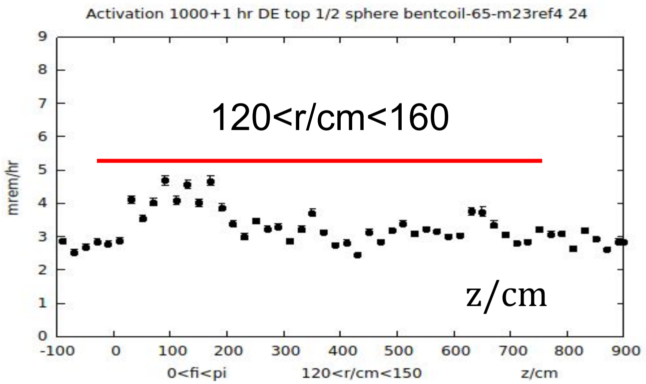
1000+1 hr Activation DE (mrem/hr) at r=150-180 cm from beam 3.5 mm. $B=0.9B_n$. Iron core to save lead.



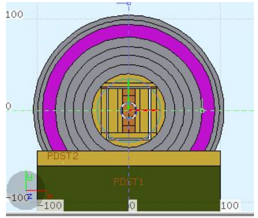




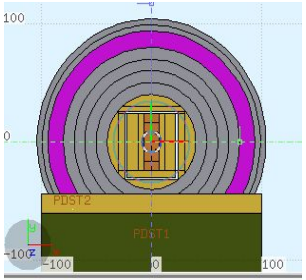


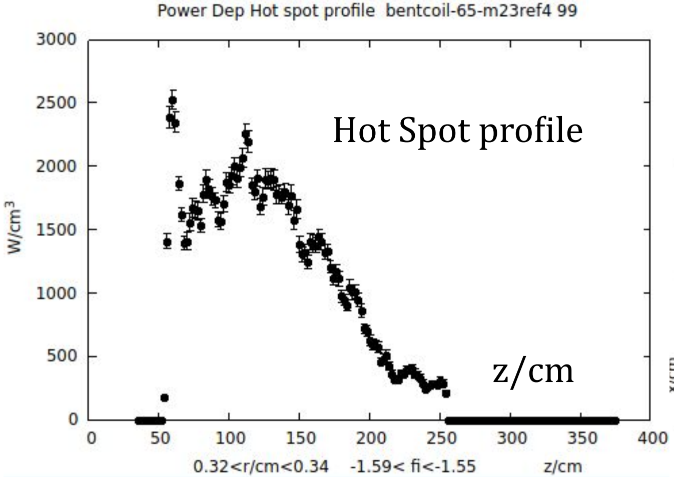


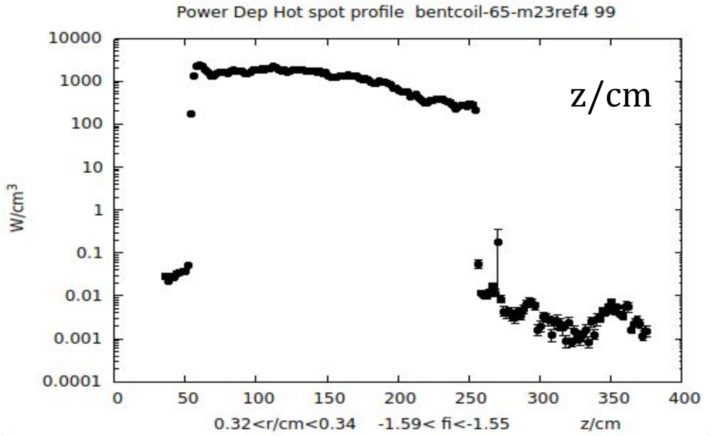
- Activation is below 5 mrem/hr !

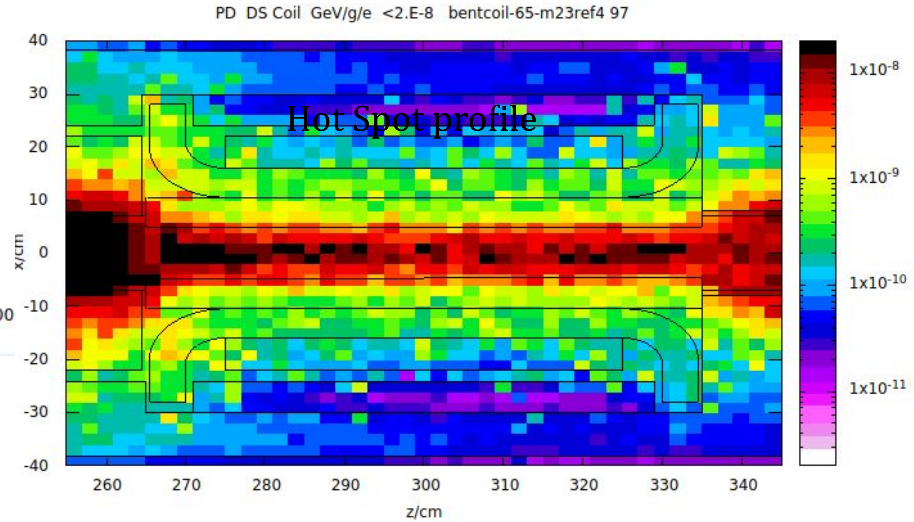


Beam 3.5 mm. B=0.9B_n. Max. dP/dV=2.5 kW ; Coil Lifetime =300 years.

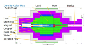




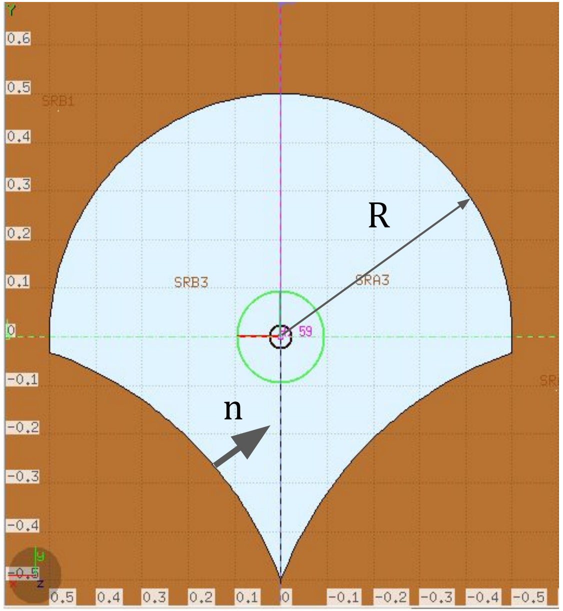




- Prompt dose in DS coil <**2.E-9 GeV/g/e**.
- Coil LT ~ **300 years**.



Beam 2.5 mm. PDE and Activation.
"Stingrey" beam channel.
Shield Optimization.



R=0.5 cm ; may be higher.

$\mathbf{n_b}$ - beam direction

ϑ -pitch angle to the tangent surface **n.**

$(\mathbf{n_b}, \mathbf{n}) = \sin(\alpha)\sin(\varphi) = \sin(\vartheta)$

α -beam pitch angle to the screen normal.

φ -angle between n and horiz. axis.

Comments to the video. What is the wedge effect?

1) Consider e-**beam as a cylinder diameter D** with uniform density; direction $\mathbf{n_b}=(0,\sin(\alpha),\cos(\alpha))$,
where α pitch angle to the beam axis.

2) For a **squared or wedge-like** channels the **hot spot is a cross section of a cylinder with a plane**.
Plane orientations: $\mathbf{n_1}=(0,1,0)$ -for **squared** channel, or $\mathbf{n_2}=(\pm\cos(\varphi),\sin(\varphi),0)$ - for 2 **wedge** planes
obtained as $\pm\varphi$ - rotation of yz-plane around z-axis.
Impact angle is determined by $(\mathbf{n_b}, \mathbf{n_1}) = \sin(\alpha)$ or $(\mathbf{n_b}, \mathbf{n_2}) = \sin(\alpha)\sin(\varphi) = \sin(\vartheta)$ - pitch to wedge plane.

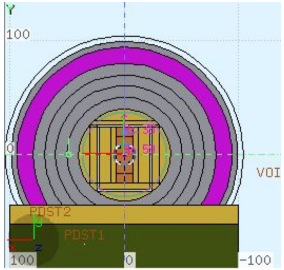
3) But in both cases the **intersection is an ellipse** with the area $S = \pi D \times L$, where **L** - ellipse large axis.

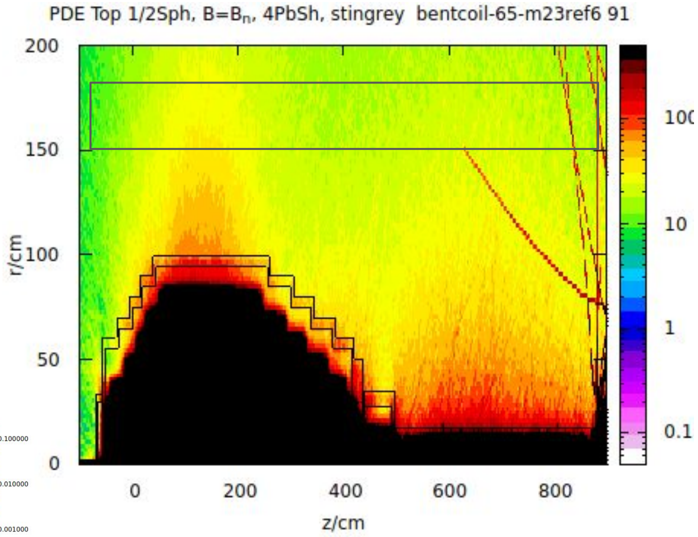
4) Pitch angle $\vartheta \sim D/L$.

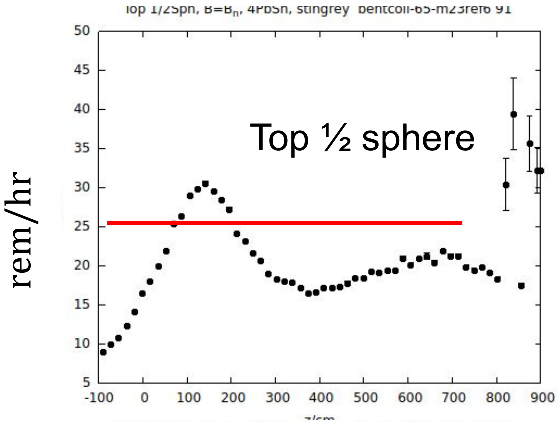
5) Maximum **L is constrained by the length** of the **beam channel** ($L<L_c\sim 2$ m), or the **wedge** ($L<L_w\sim 0.5$ m).

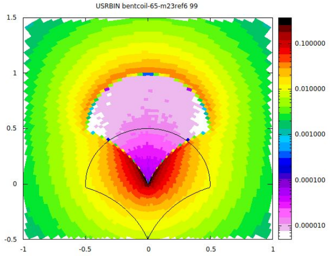
- **Therefore max $dP/dS \propto \vartheta \propto L^{-1}$ for the wedge is $L_c/L_w = 4$ times higher.**

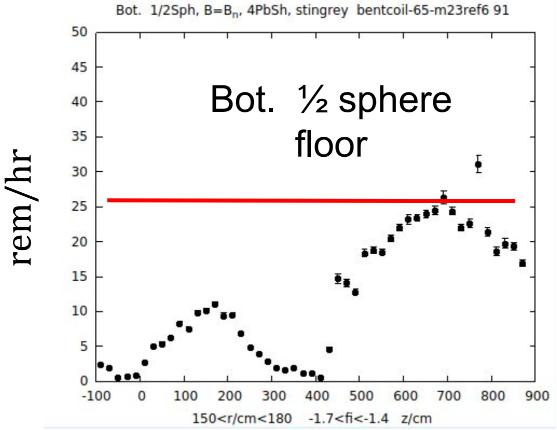
B=B_n, "stingray" chanel d=1 cm, 4 layers of Lead. More W-shield for DS Coil.





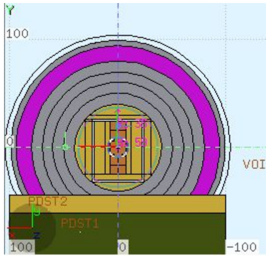


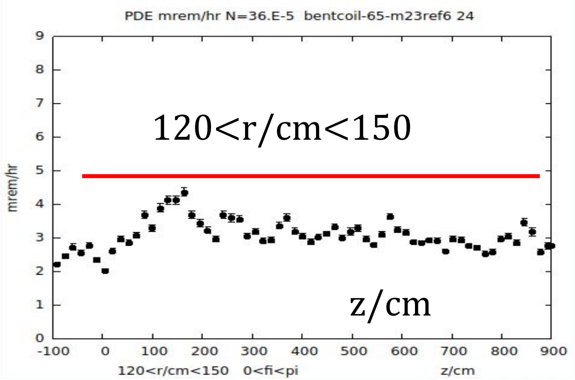


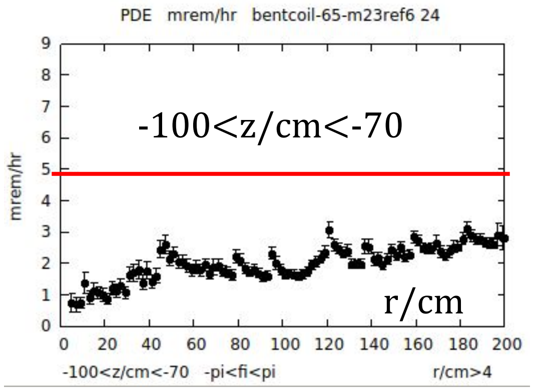


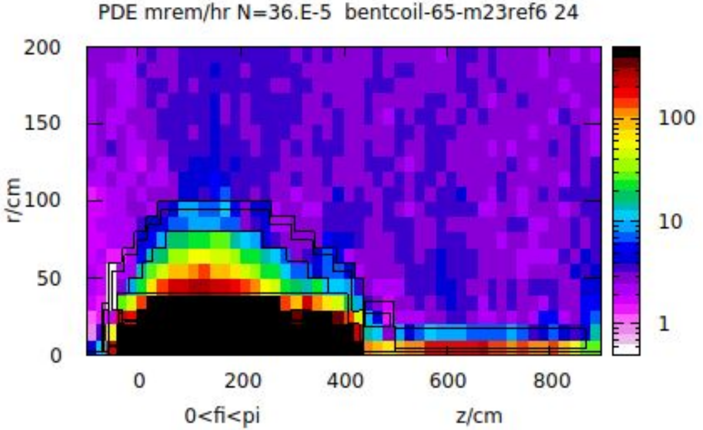
- PDE meets requirement of PAC48 for the floor level.

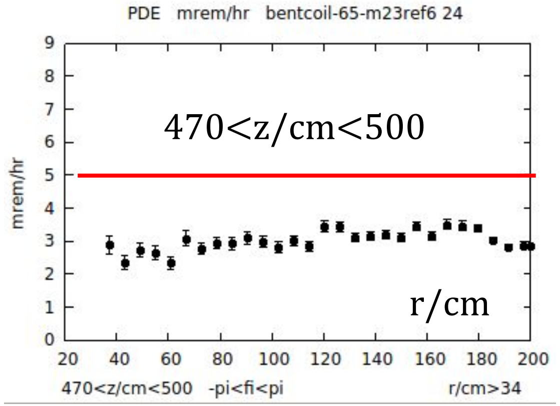
1000+1 hr Activation DE (mrem/hr) ; beam 2.5 mm, $B=B_n$. Iron core. "Stingrey" channel.





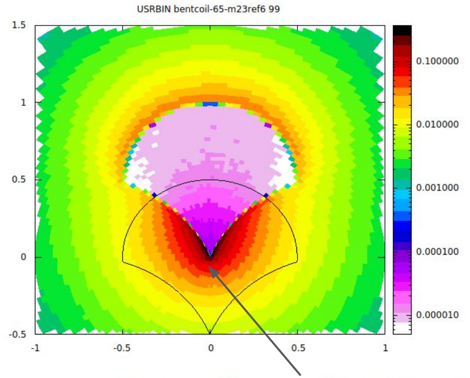


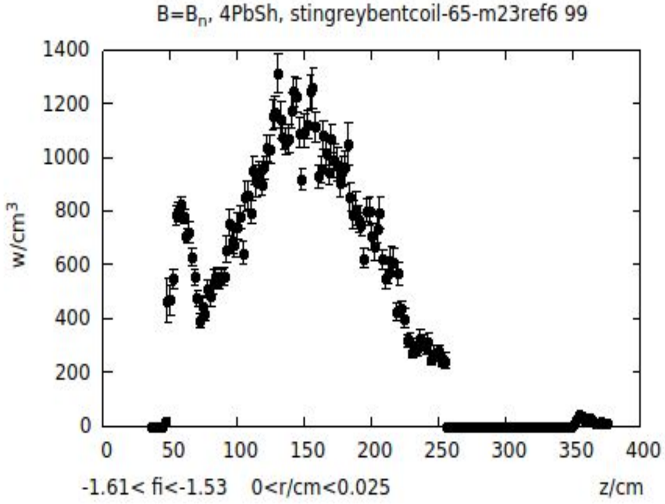


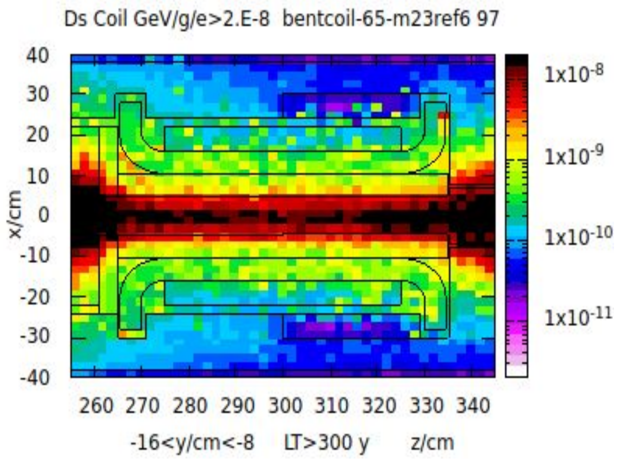


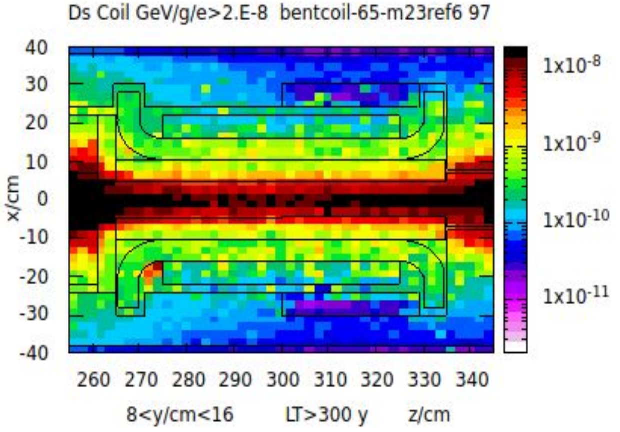
- Activation is below 5 mrem/hr.

Beam σ=2.5 mm. B=B_n. dP/dV < 1.2 kW ; Coil Lifetime ~300 years.



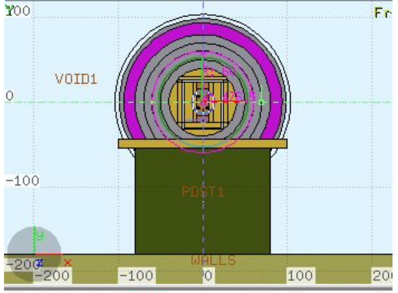


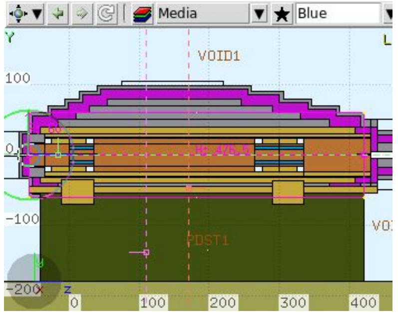


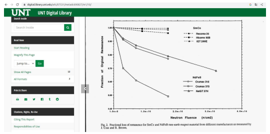


CPS Weight and Cost estimates.

1	Pb Skin	g/cm3	z	dZ	R	Xint	X-fct	V/cm3	P/T	P/T	Cost	
2	ski5 z.dz.r	11.4	40	220	99	88.7	0.65	7.60E+5	8.7			
3	ski1	11.4	15	290	90	78.6	0.66	1.03E+6	11.7			
4	ski2	11.4	-6	351	80	66.5	0.69	1.13E+6	12.9			
5	ski3	11.4	-30	415	70	54	0.72	1.22E+6	13.9			
6	ski4	11.4	-56.5	476.5	60	40.5	0.76	4.11E+6	-37.0			
7	V_tot				0			8.25E+6	10.2	10.2	$50,996	
8	V_filled		g/cm3=	11.4	$/kg=	5		8.95E+5	10.2			
9	B+Polyethyl.		z	dZ	R	Xint	X-fct					
10	bor5	1.2	45	211	94	82.4	0.66	7.01E+5	0.8			
11	bor1	1.2	20	280	85	72.4	0.67	9.48E+5	1.1			
12	bor2	1.2	-1	341	75	61	0.70	1.05E+6	1.3			
13	bor3	1.2	-25	405	65	47	0.74	1.13E+6	1.4			
14	bor4	1.2	-51	467	55	33	0.80	3.53E+6	-2.2			
15	V_tot				0			7.36E+6	2.4	2.4	$47,278	
16	V_filled		g/cm3=	1.2	$/kg=	20		1.97E+6	2.4			
17	Lead Shield		z	dZ	R	Xint	X-fct					
18	les19	11.4	55	190	80	66.6	0.69	6.14E+5	7.0			
19	les16	11.4	30	260	70	54	0.72	7.62E+5	8.7			
20	les15	11.4	10	320	60	41	0.76	8.42E+5	9.6			
21	les14	11.4	-15	385	50	24	0.84	9.16E+5	10.4			
22	les13	7.8	-41	448	40	0	1.00	2.25E+6	3.4			
23	V_tot							5.39E+6	39.2	39.2	$195,838	49
24	V_filled		g/cm3=	11.4	$/kg=	5		3.58E+6	40.8			
25	Iron Core		z	Z	dy	dx						
26	Void z,Z,x,y		-56.5	430	62	60		1.81E+6				
27	V_tot							1.81E+6				
28	V_filled		g/cm3=	7.87	$/kg=	4		1.48E+6	11.7	11.7	$46,680	
29	Cu Absorber		-56.5	430	48	14		3.27E+5				
30	V_tot							3.27E+5				
31	V_filled		g/cm3=	8.96	$/kg=	20		3.27E+5	2.9	2.9	$58,585	
32	Pedestal Con.		-40	420	126	100		5.80E+6				
33	V_tot							5.80E+6				
34	V_filled	2.3	g/cm3=	2.3	$/kg=	3		5.80E+6	13.3	13.3	$39,992	
35	Platform Fe		-56.5	430	10	200		9.73E+5				
36	V_tot							9.73E+5				
37	V_filled		g/cm3=	7.87	$/kg=	4		9.73E+5	7.7	7.7	$30,630	
41									All	87.3	$470,001	
42									-Pdst	74.0	$430,008	
43									-Pltf	66.3	$399,378	

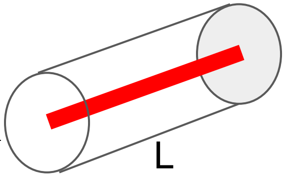






CPS Mat.	Ton	g/cm3	$/kg
Lead	49	11.3	5
B+PE	2.4	1.2	20
Iron	12	7.8	4
Copper	2.9	8.9	20 (100,Tim)?
Total CPS	66	-	(+$240,000)

CPS critical sizes and shield optimization.



Consider a source of radiation (red line) and a shield around it (cylinder R,L). Stationary case.

Total **power P of red line** relates to **dP/ds** at the **cylinder surface** as

$$\mathbf{P=2\pi RL\,(dP/ds)}$$

Assume $dP/ds = \varrho$ is constrained by RadCon regulations to be constant at varying sizes.

=> for the SPS radius we write $\mathbf{R= (P/\varrho)(2\pi L)^{-1}}$

For the CPS cyl. volume we write:

$$\mathbf{V}=\pi(2\pi)^{-2}\,\mathbf{L^{-1}(P/\varrho)^2}$$

For a spherical case

$$\mathbf{V}=(4\pi/3)(4\pi)^{-3/2}\mathbf{(P/\varrho)^{3/2}}$$

And we find that for constrained $dP/ds= \varrho$ at CPS surface

CPS volume $V \propto L^{-1}$

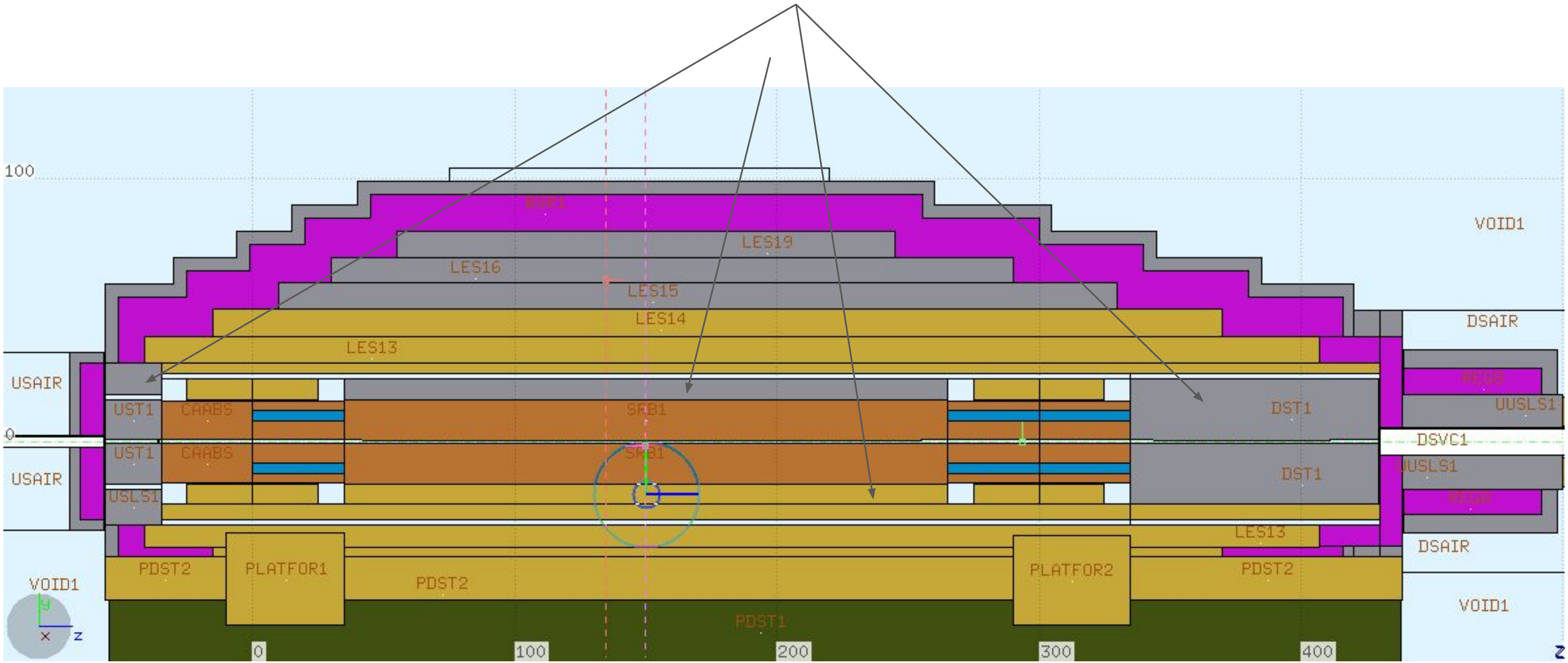
Temperature $T^o \propto L^{-1}$ (from the previous presentations)

Magnet power $B \propto L^{-1}$

Max. power dep. $dP/dz \propto L^{-1}$

- Thus, further **increasing CPS length L we may save on volume, weight, and magnet cos**t.
- Electron beam current is limited by Absorber temperature.
- Photon beam intensity may be significantly higher.

If copper cost is $100/kg we may replace Cu with Fe or Pb in some locations



Shield optimization requires FLUKA and Temperature calculations.

FLUKA Absorbed Dose (rad/Gy) and Dose Equivalent (rem/Sv).

Equivalent Dose definition.

Calculating equivalent dose from absorbed dose;

$$H_T = \sum_R W_R \cdot D_{T,R}$$

where

H_T is the equivalent dose in sieverts (Sv) absorbed by tissue T,

$D_{T,R}$ is the absorbed dose in grays (Gy) in tissue T by radiation type R and

W_R is the radiation weighting factor defined by regulation.

- Does FLUKA follow standard rules?

Absorbed dose includes neutrons.

Radiation weighting factors W_R (formerly termed Q factor) used to represent relative biological effectiveness according to ICRP report 103[6]

Radiation	Energy	W_R (formerly Q)
x-rays, gamma rays, beta particles, muons		1
neutrons	< 1 MeV	$2.5 + 18.2 \cdot e^{-[\ln(E)]^2/6}$
	1...50 MeV	$5.0 + 17.0 \cdot e^{-[\ln(2 \cdot E)]^2/6}$
	> 50 MeV	$2.5 + 3.25 \cdot e^{-[\ln(0.04 \cdot E)]^2/6}$
protons, charged pions		2
alpha particles, fission products, heavy nuclei		20