Radiation studies for Mu2e magnets

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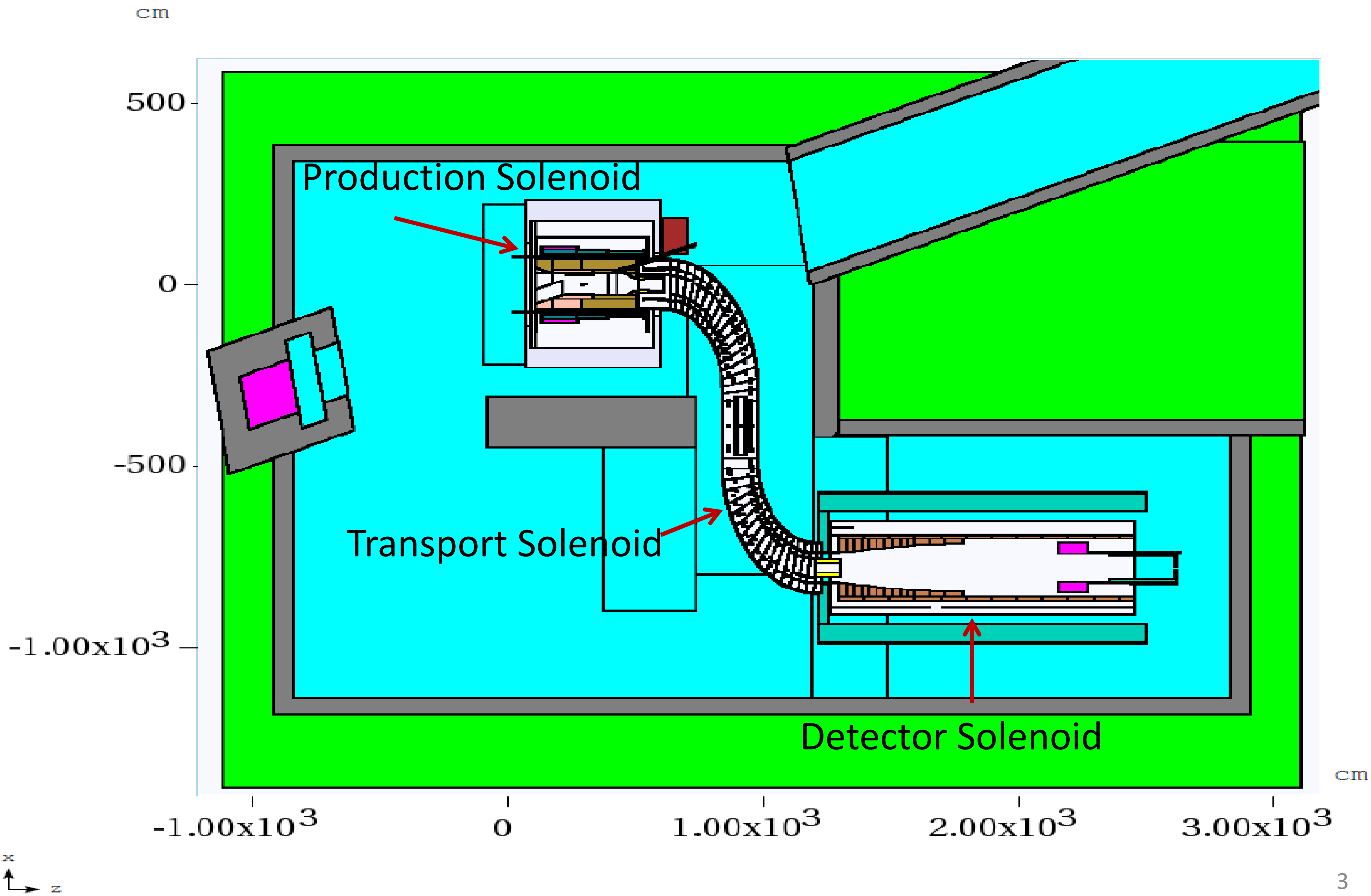
Outline

- Requirements on radiation quantities for Mu2e cryogenics
  - Dynamic heat load
  - Power density
  - Absorbed dose
  - DPA
- Production Solenoid Heat and Radiation Shield design. MARS15 modeling
  - Shape optimization
  - Material optimization
  - Current model
- Preliminary Mu2e@ProjectX PS design
- Conclusions

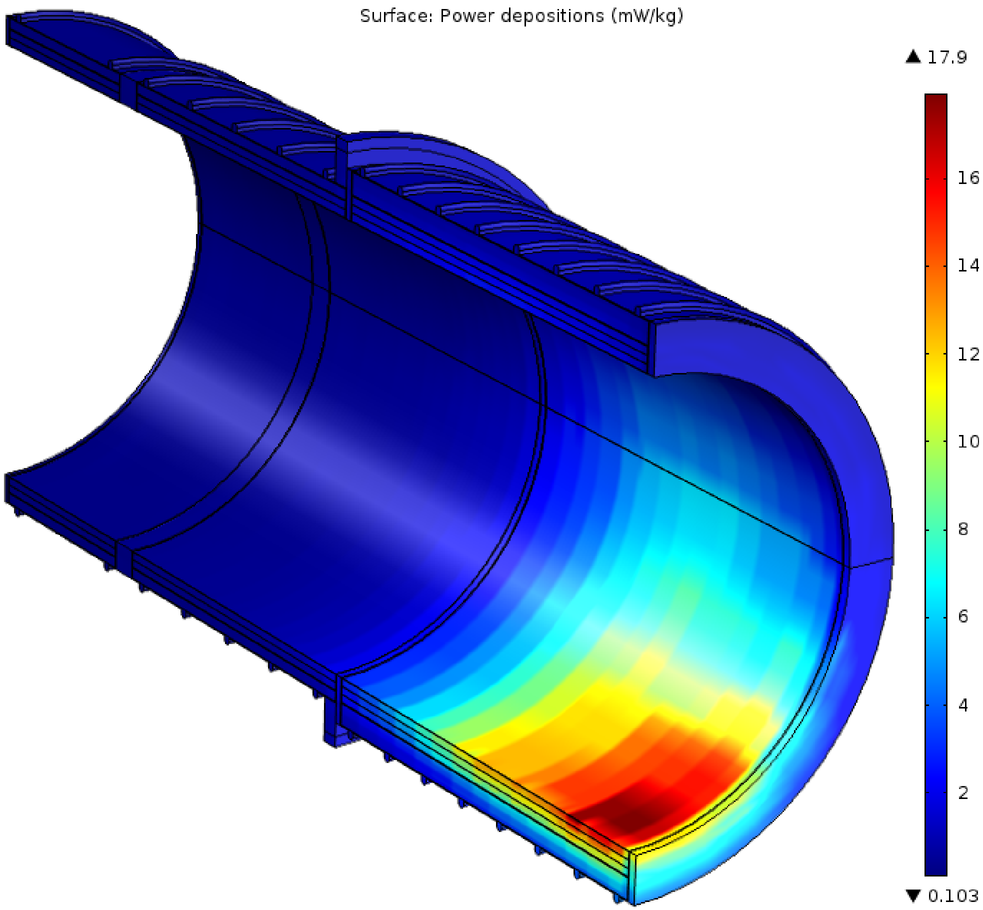
Mu2e hall MARS15 model

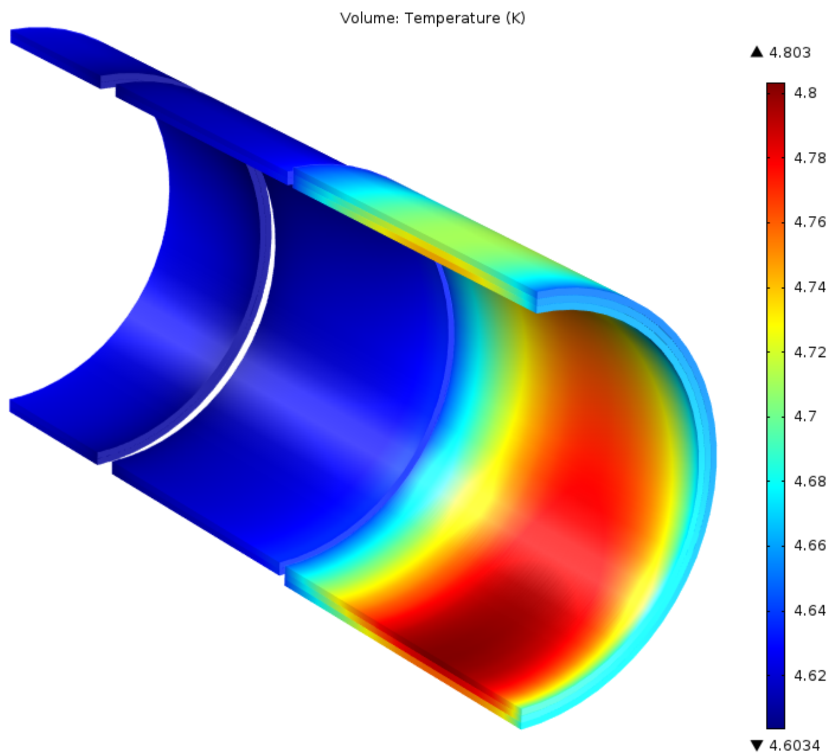


Requirements to Heat and Radiation Shield

- Absorber (heat and radiation shield) is intended to prevent radiation damage to the magnet coil material and ensure quench protection and acceptable heat loads for the lifetime of the experiment
  - Total dynamic heat load on the coils (100 W)
  - Peak power density in the coils
  - Peak radiation dose to the insulation and epoxy
  - DPA to describe how radiation affects the electrical conductivity of metals in the superconducting cable

Requirements. Peak power density





T_c = 6.5K; (supercond+field)

T_{peak} = T_c-1.5K = 5.0K.

T0 shall be < 4.7K (liquid He temp)

See talk of Vadim Kashikhin

Absorbed dose 350kGy/yr (0.017 mW/g)

Requirements. Absorbed dose

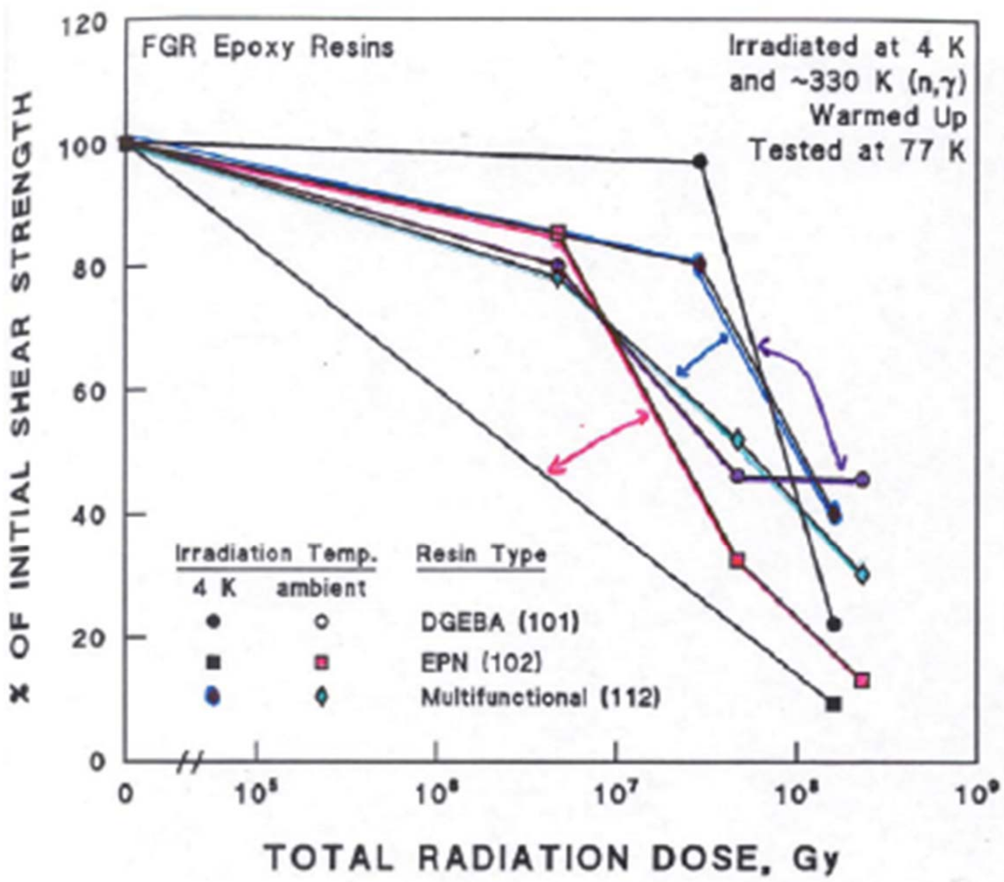


Figure 1.25. A comparison of the shear strengths of three types of reinforced epoxy resins that were reactor-irradiated at both 4 K and at ambient temperature. See text for differences in the fast neutron spectrum in the two reactors. Data from Munshi [1991]. (Supplementary Tables A. 3-3 and A. 8-4.)

7 MGy before 10% degradation of shear modulus.

350 kGy/yr -> 20 years lifetime

Radiation Hard Coils, A. Zeller et al, 2003, http://supercon.lbl.gov/WAAM

Requirements. DPA

RRR(DPA) = $\frac{\rho_{hi}}{\rho_0+\Delta\rho(DPA)}$

ρ_{hi} = 2.7E-6 Ω*cm

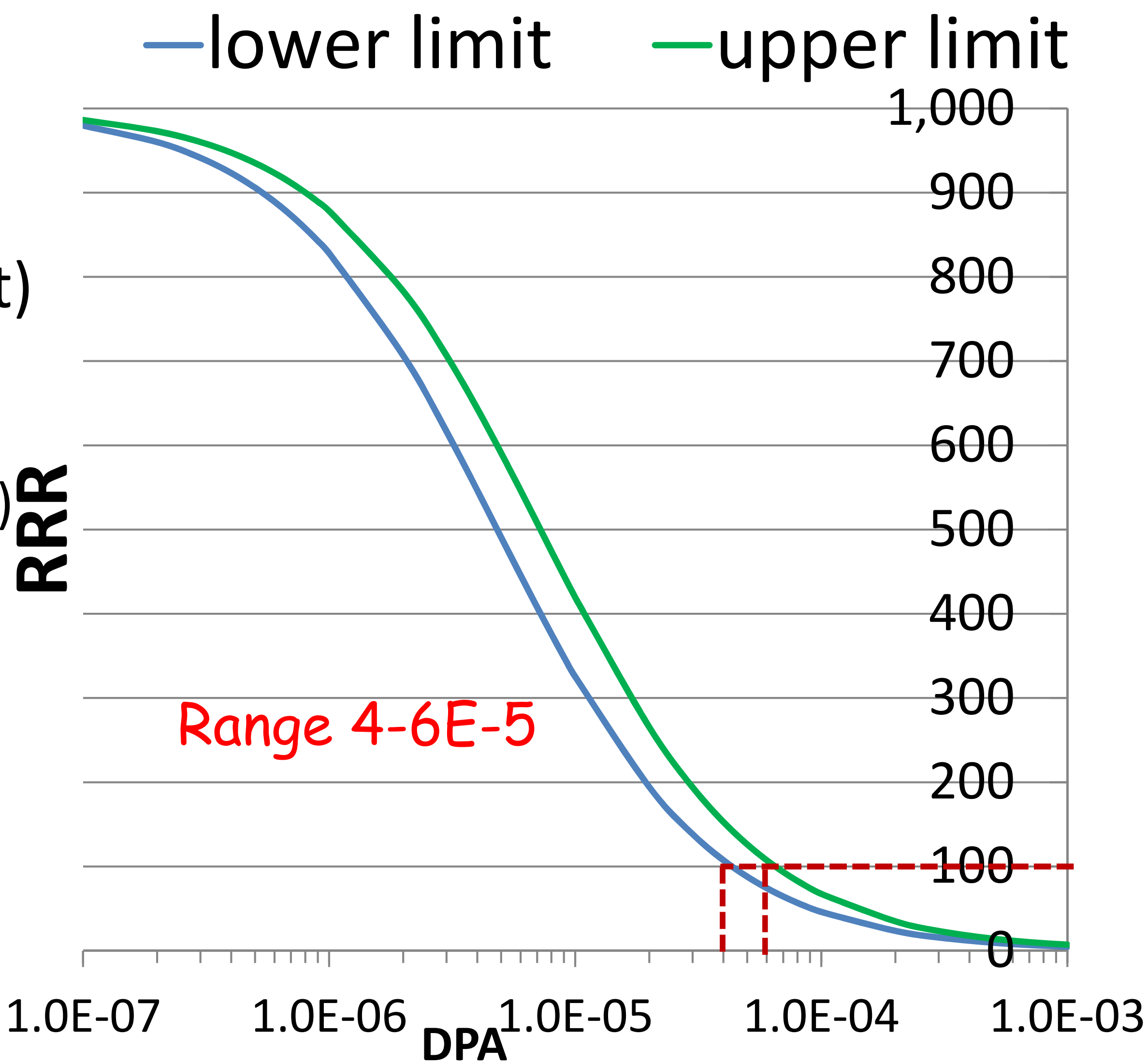
ρ_0 = $\frac{\rho_{hi}}{1000}$ (Mu2e requirement)

$\Delta\rho$ – from KEK measurement (RRR degradation from 457 to 245)

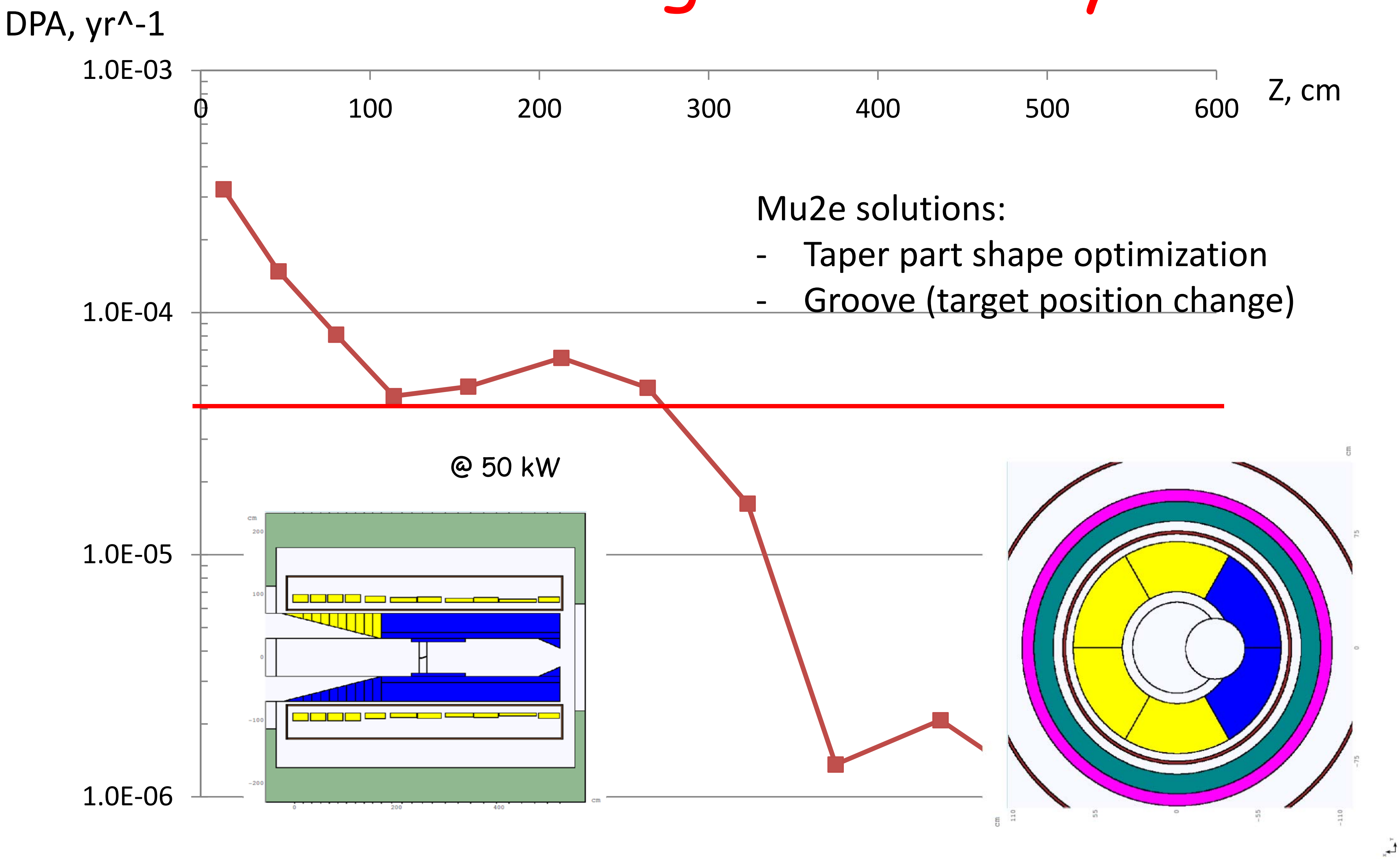
$\frac{\Delta\rho}{DPA}$ - DPA using NRT model with correction for defect production efficiency η

$$\eta = \frac{N_D}{N_{NRT}}; \quad 0.357 - 0.535$$

Broeders, Konobeyev, 2004



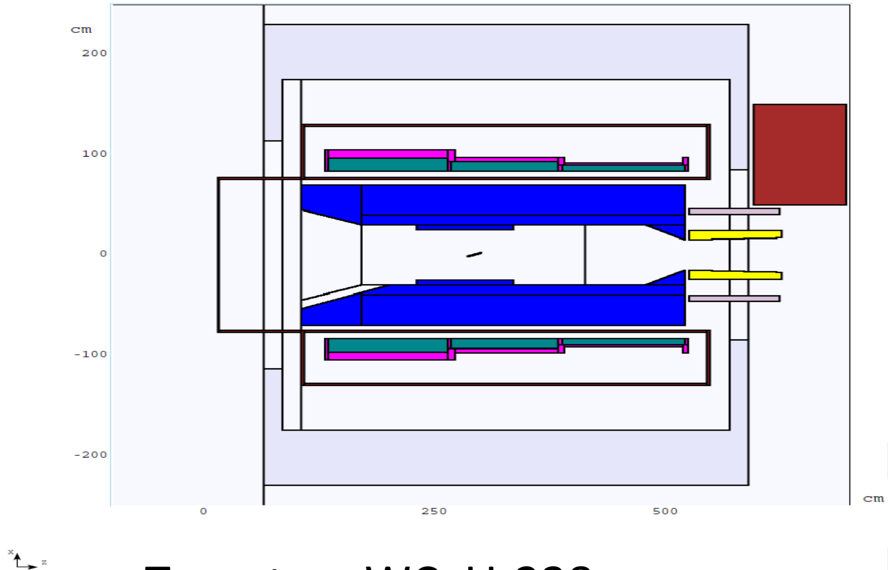
MECO design DPA analysis



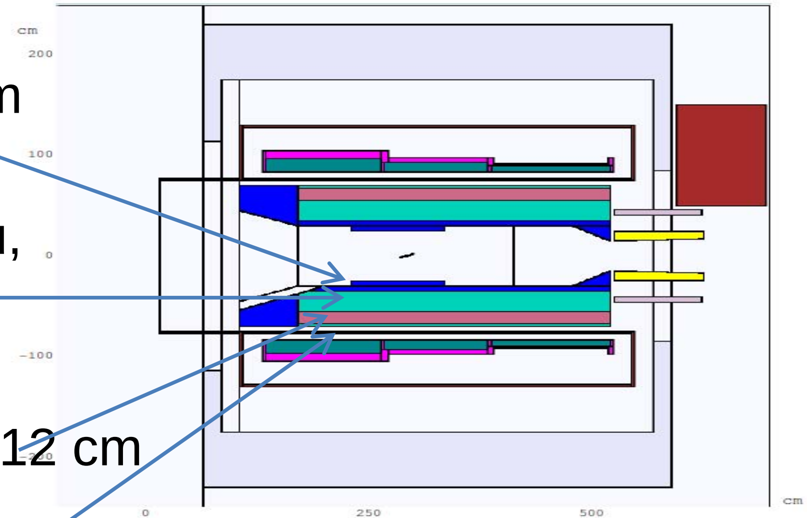
Mu2e solutions:

- Taper part shape optimization
- Groove (target position change)

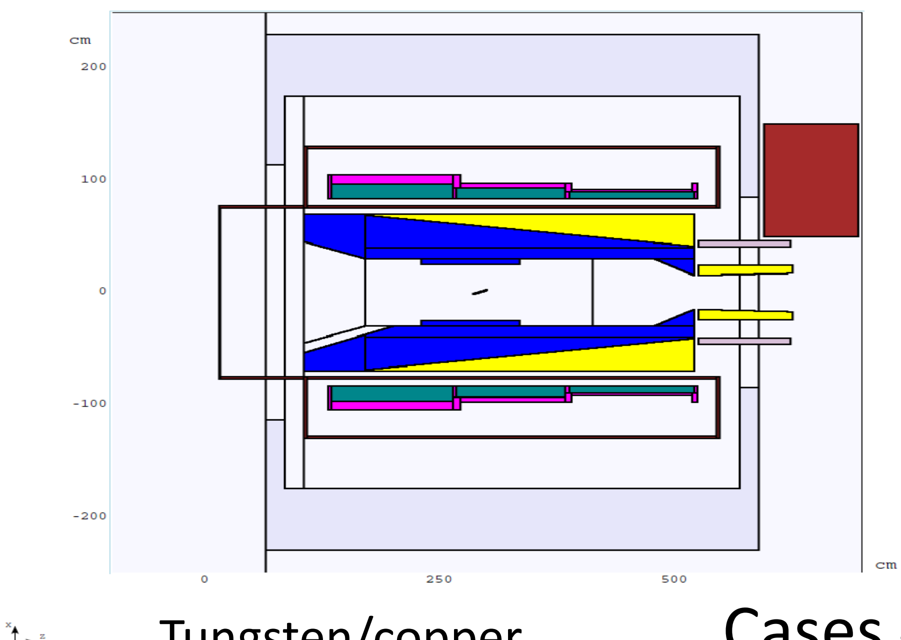
Material optimization



Tungsten, WC, U-238

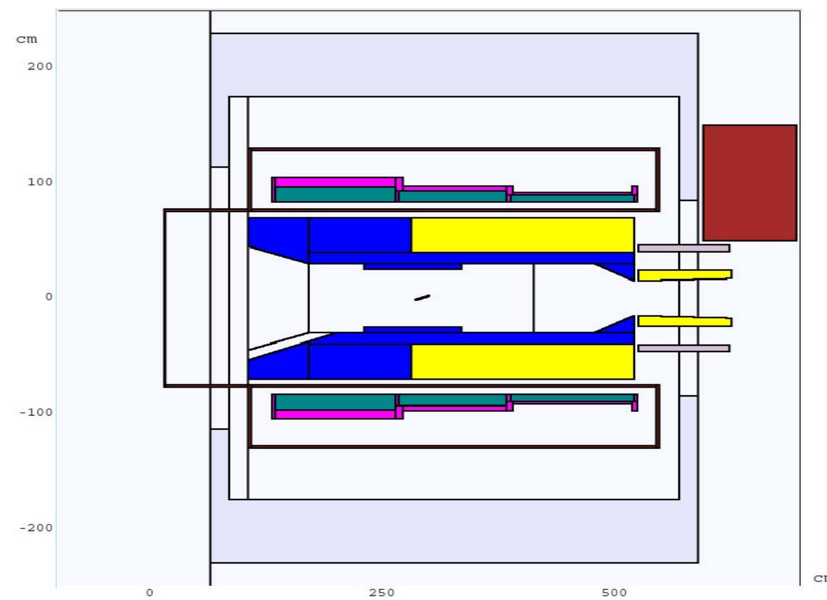


5 multilayer cases



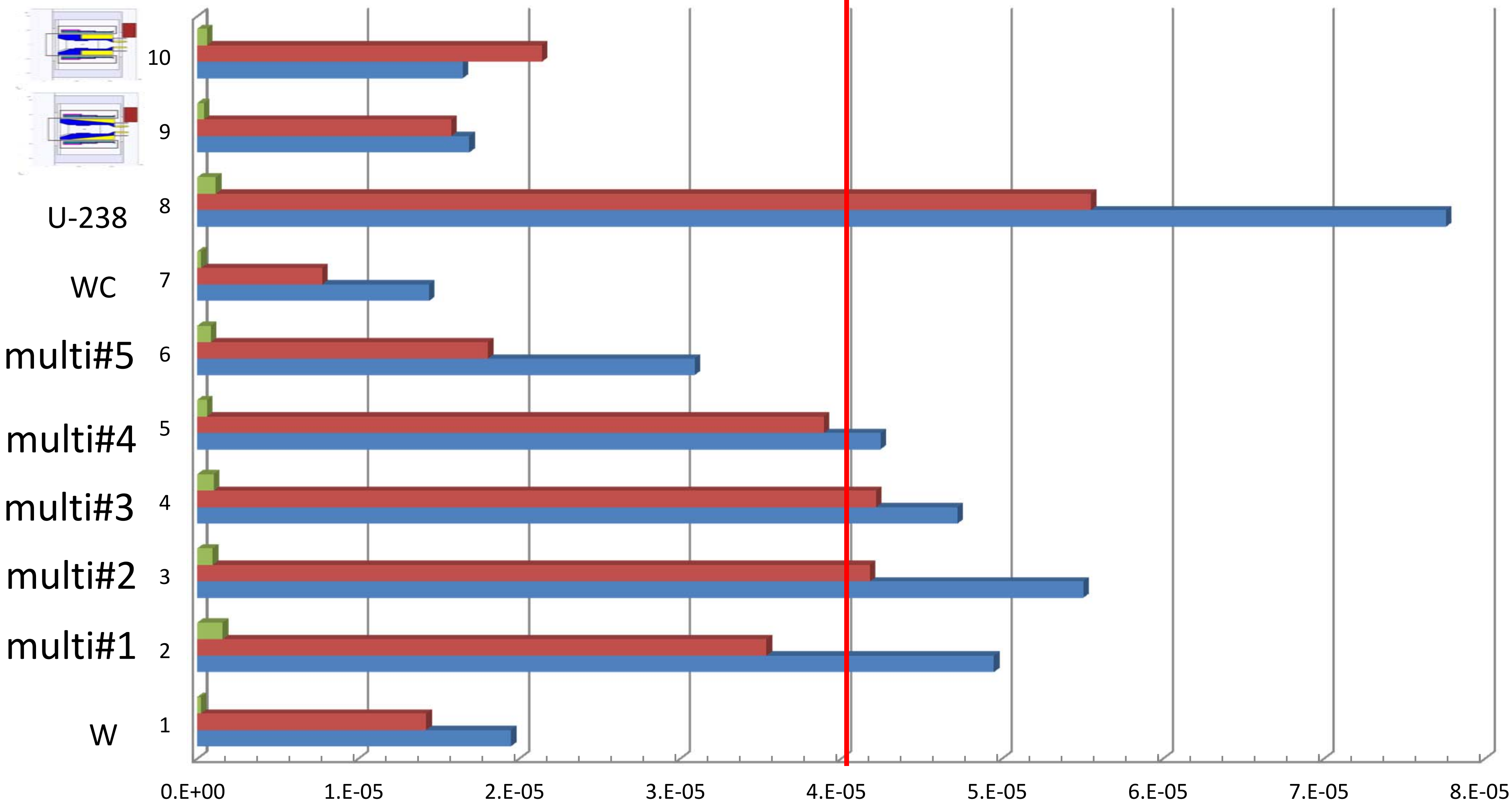
Tungsten/copper

Cases #1-#10



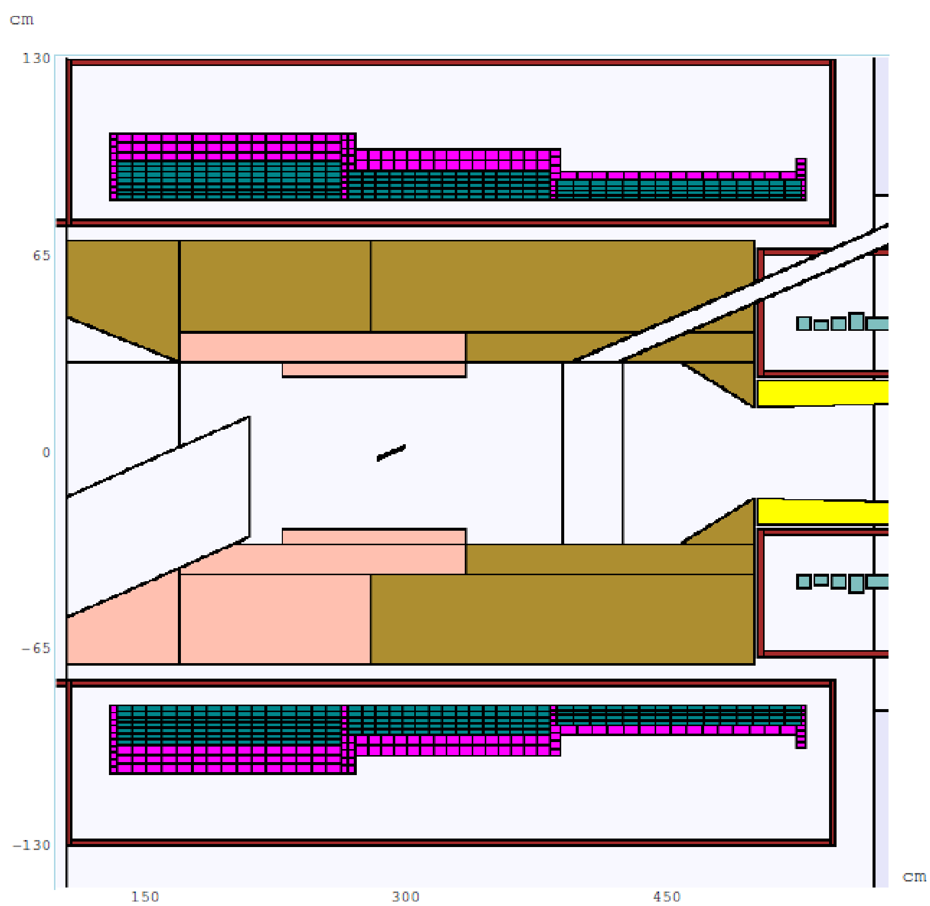
Tungsten/copper

Peak DPA in Coils, yr^-1

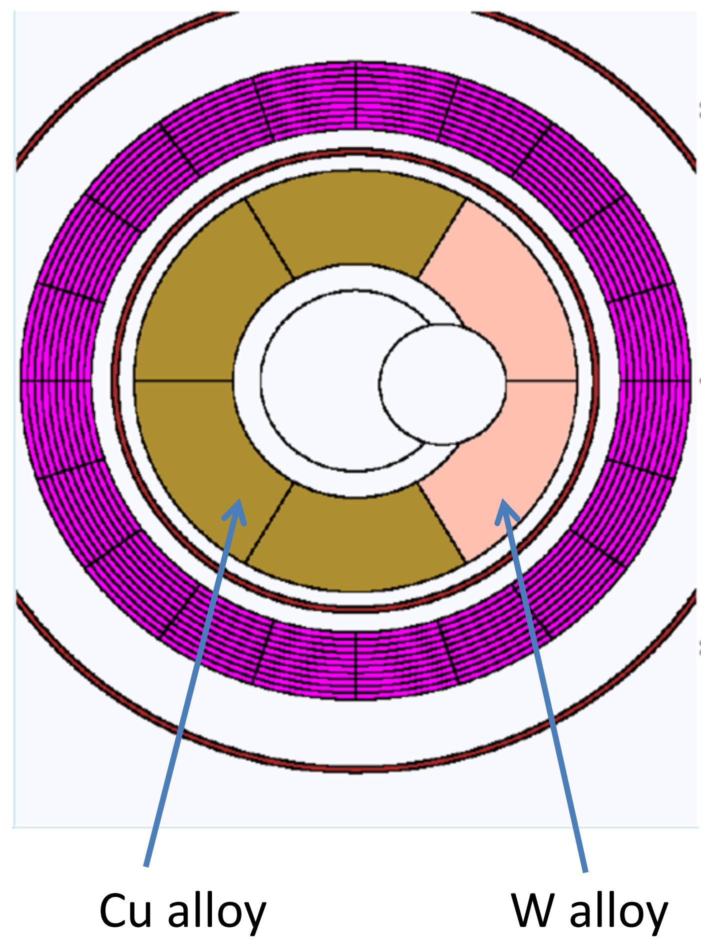


	1	2	3	4	5	6	7	8	9	10
3a	2.23E-07	1.59E-06	9.62E-07	1.02E-06	5.94E-07	8.54E-07	2.42E-07	1.16E-06	4.18E-07	5.93E-07
2a	1.42E-05	3.54E-05	4.18E-05	4.22E-05	3.89E-05	1.81E-05	7.77E-06	5.55E-05	1.58E-05	2.14E-05
1a	1.95E-05	4.95E-05	5.50E-05	4.72E-05	4.25E-05	3.09E-05	1.44E-05	7.76E-05	1.69E-05	1.65E-05

HRS model for nominal beam power

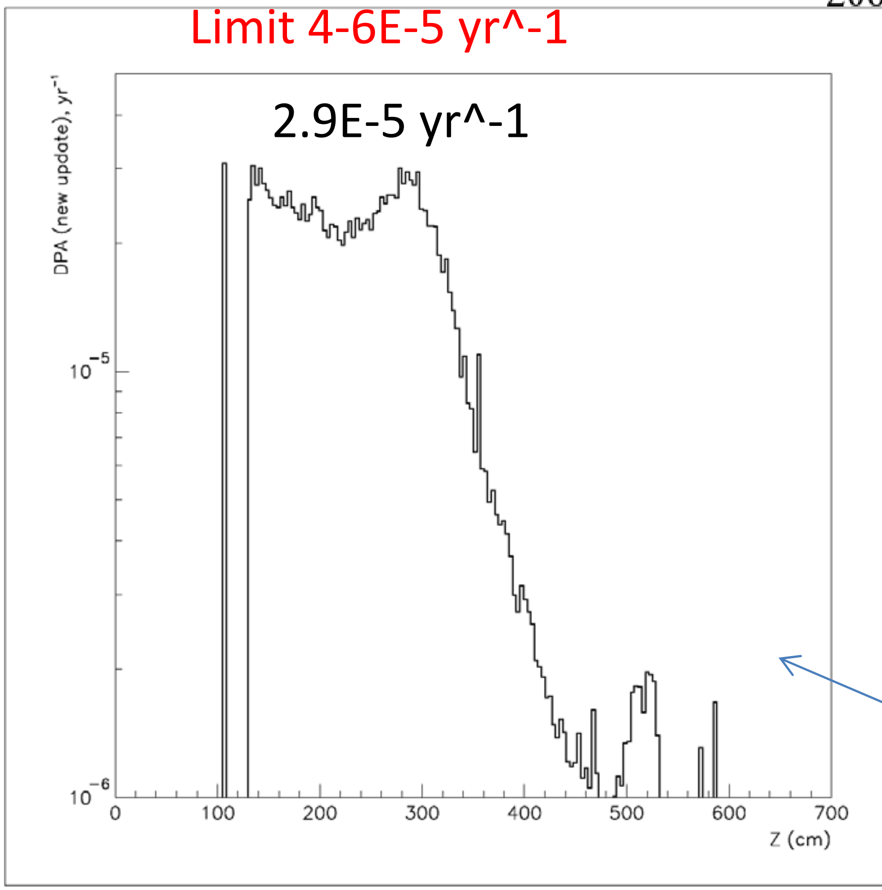


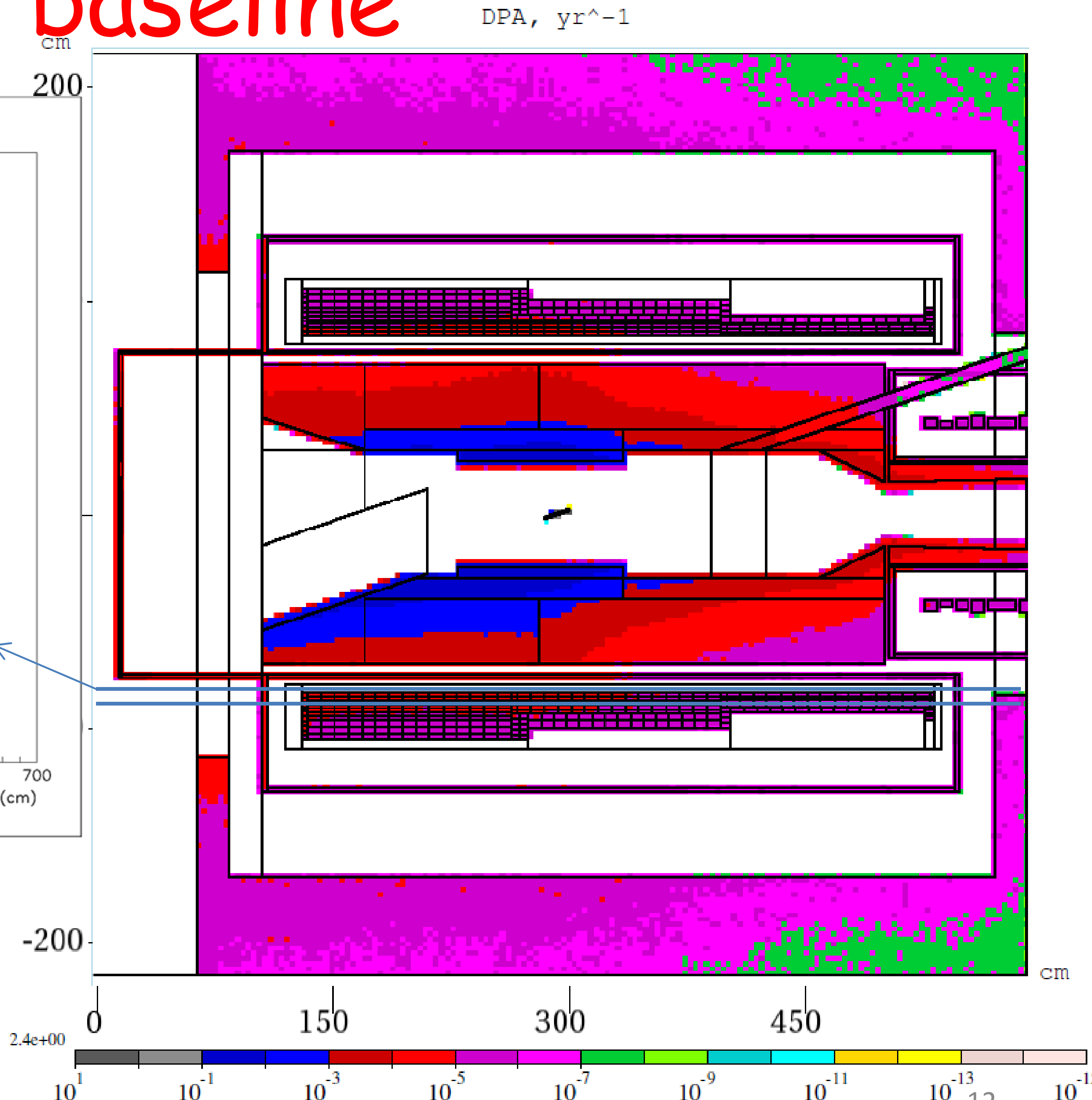
8300 zones for thermal analysis



Thresholds:
μ, ch.hadr > 1 MeV, neutrons > 0.001 eV
gamma > 200 keV, e^{+-} > 200 keV
Wedges are used in the downstream part of HS

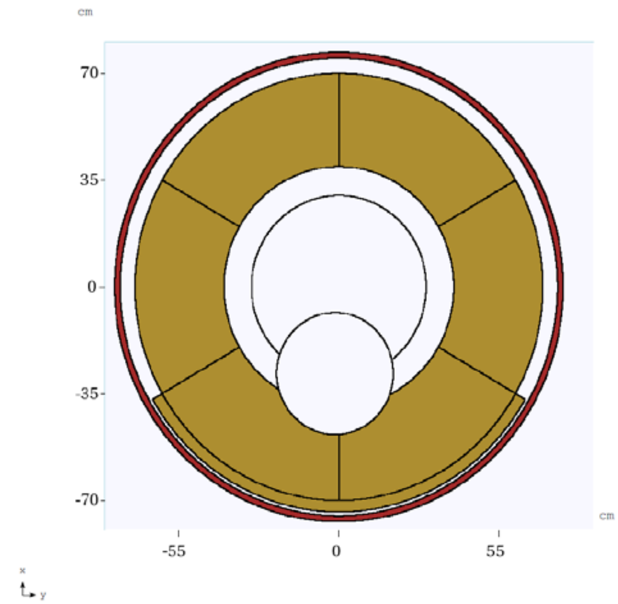
DPA for nominal beam power baseline

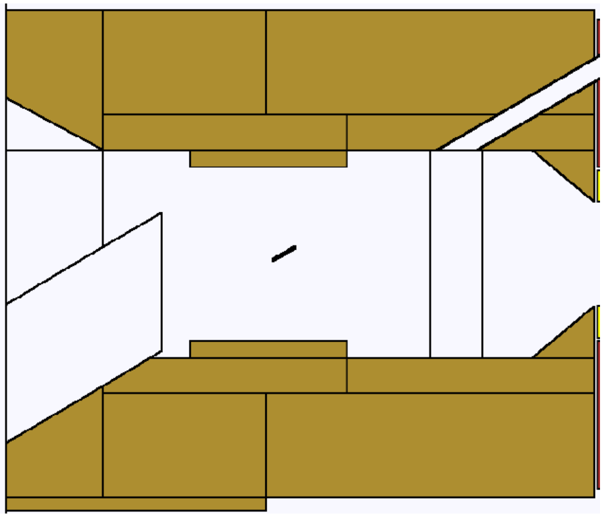




Changes to the current model

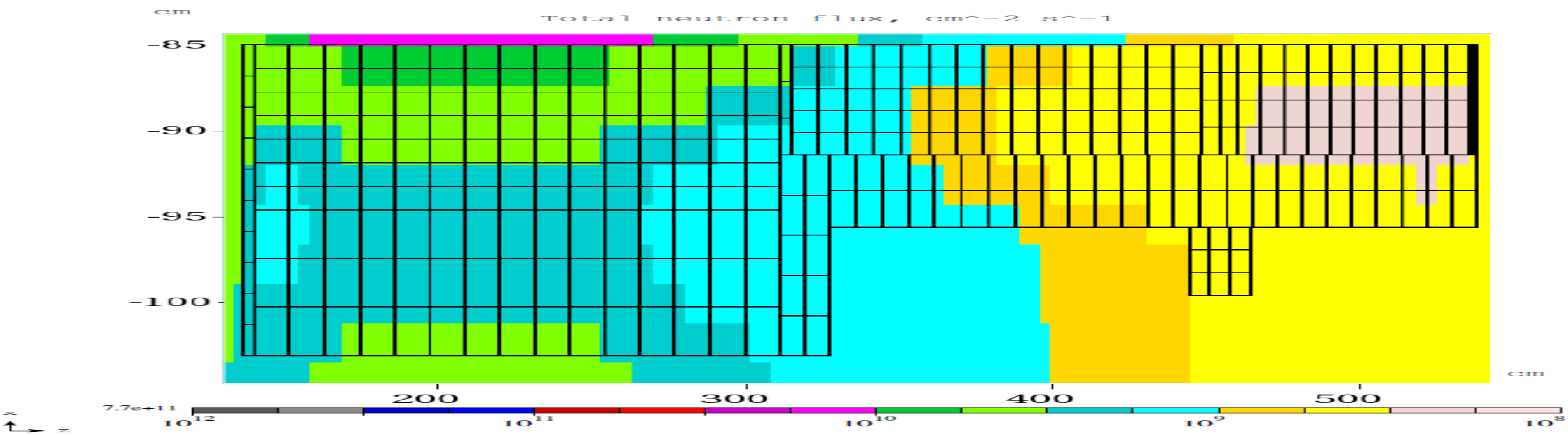
- All-bronze absorber (7.64 g/cm3)
- The exclusive model combination LAQGSM @ > A/65+1 GeV and CEM below is used
- New coil geometry
- Concrete yoke
- Fields V7 MIN (4.1 T)
  and MAX (5.0 T)
- Beam power 1/3 of nominal



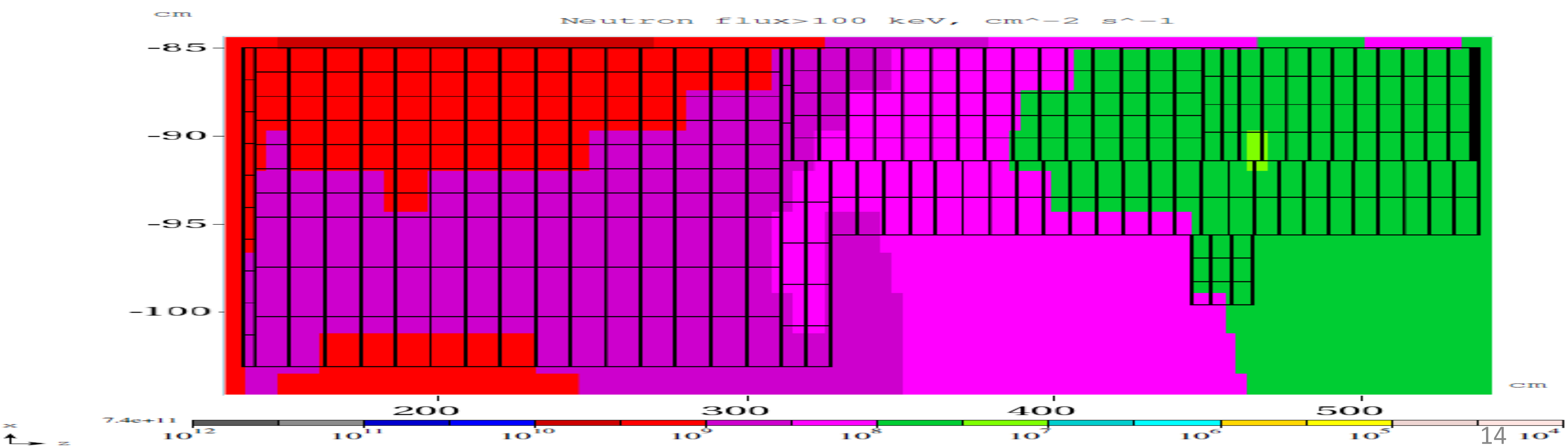


Neutron flux, total and >100 keV

Flux = 8.3E9 cm^2 s^-1 <1E22 m^-2



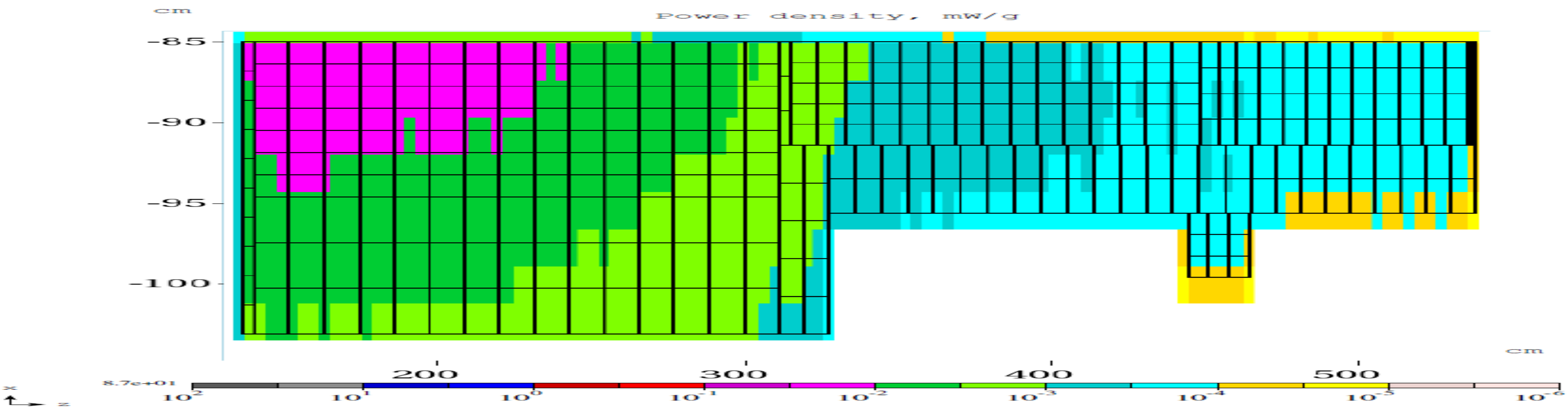
Flux = 3.0E9 cm^2 s^-1



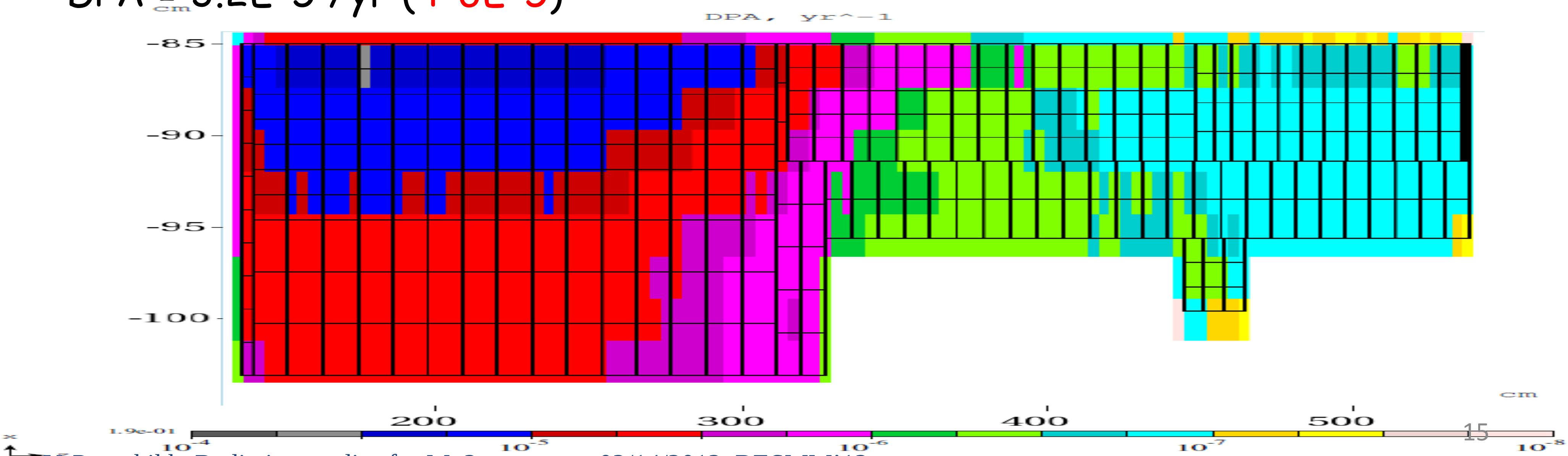
Power density, mW/g

17 uW/g

Dynamic heat load Q=20 W (100 W)



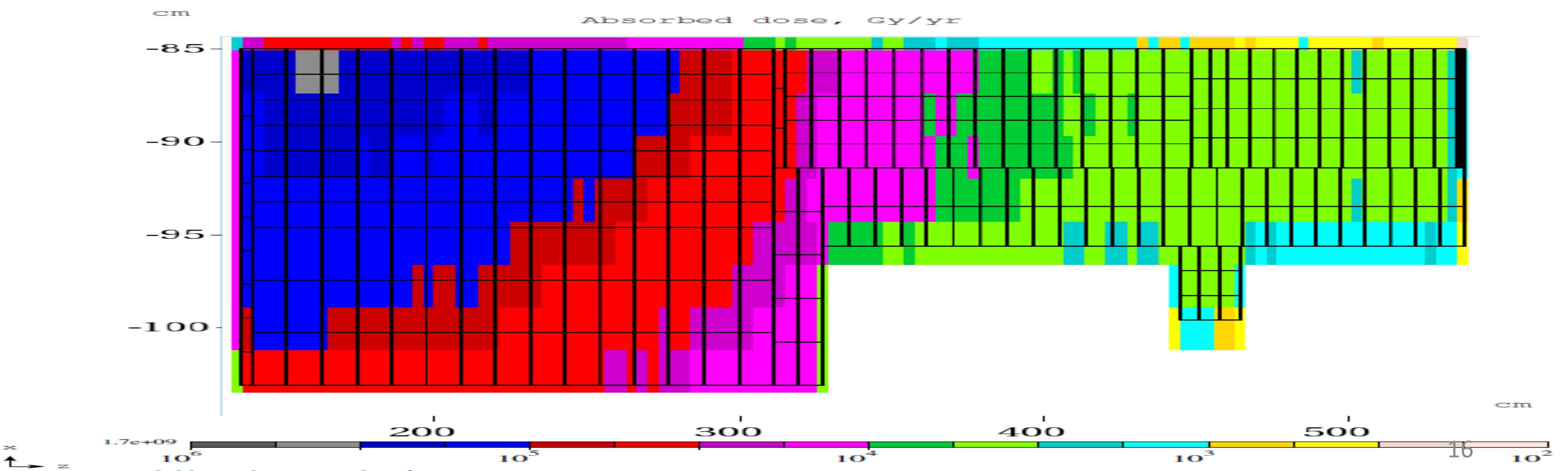
DPA = 3.2E-5 /yr (4-6E-5)



Absorbed dose. Summary table

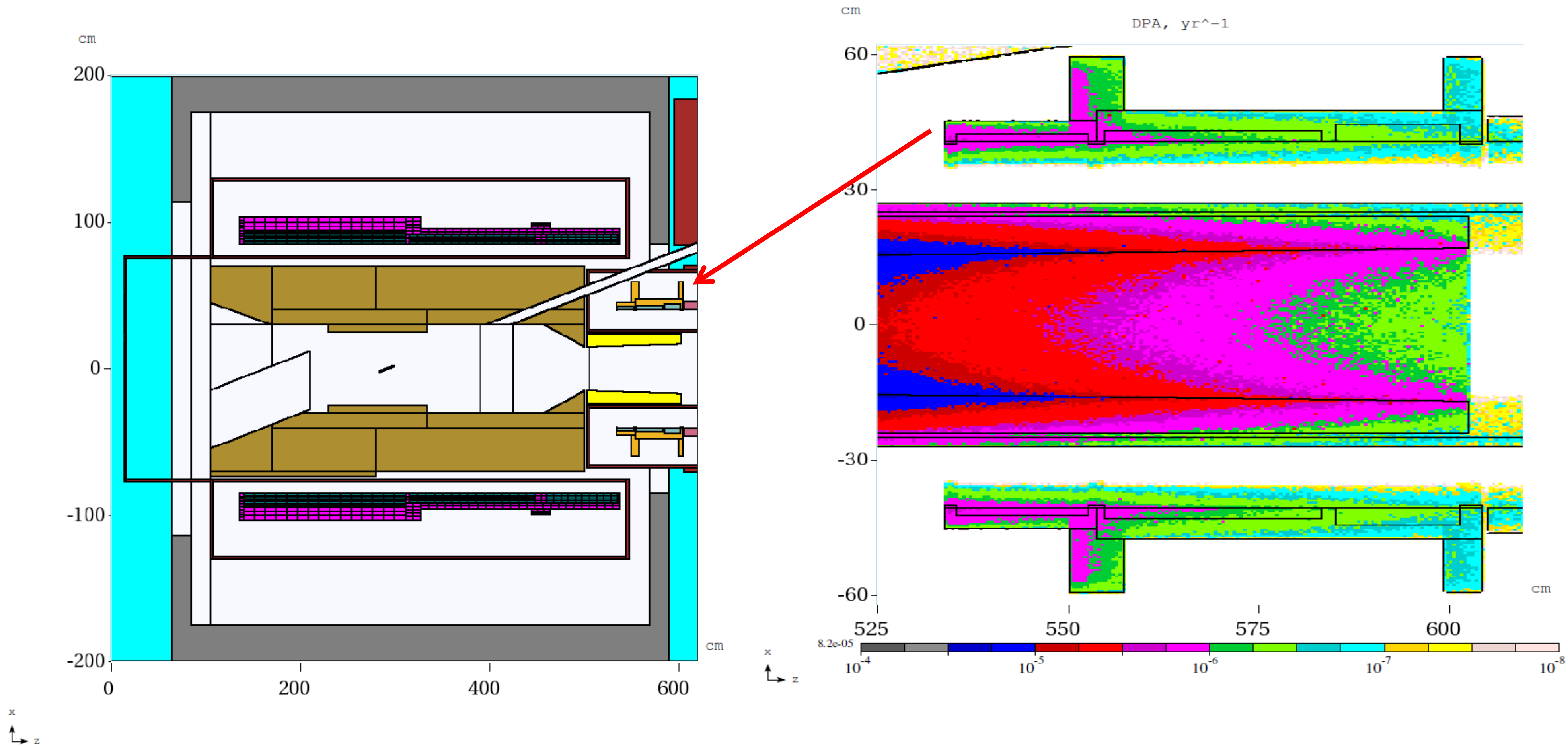
Quantity\Model	LAQGSM+CEM, MIN f.	LAQGSM+CEM,MAX f.	Default, MIN
T. Neutron flux n/cm2/s	8.5E9	8.3E9	7.9E9
HE Neutron flux n/cm2/s	3.1E9	3.0E9	2.4E9
Power density, uW/g	16	17	9
DPA, /yr	3.1E-5	3.2E-5	2.4E-5
Absorbed dose, kGy/yr	330	330	170

Dose = 330 kGy/yr (350 kGy/yr)

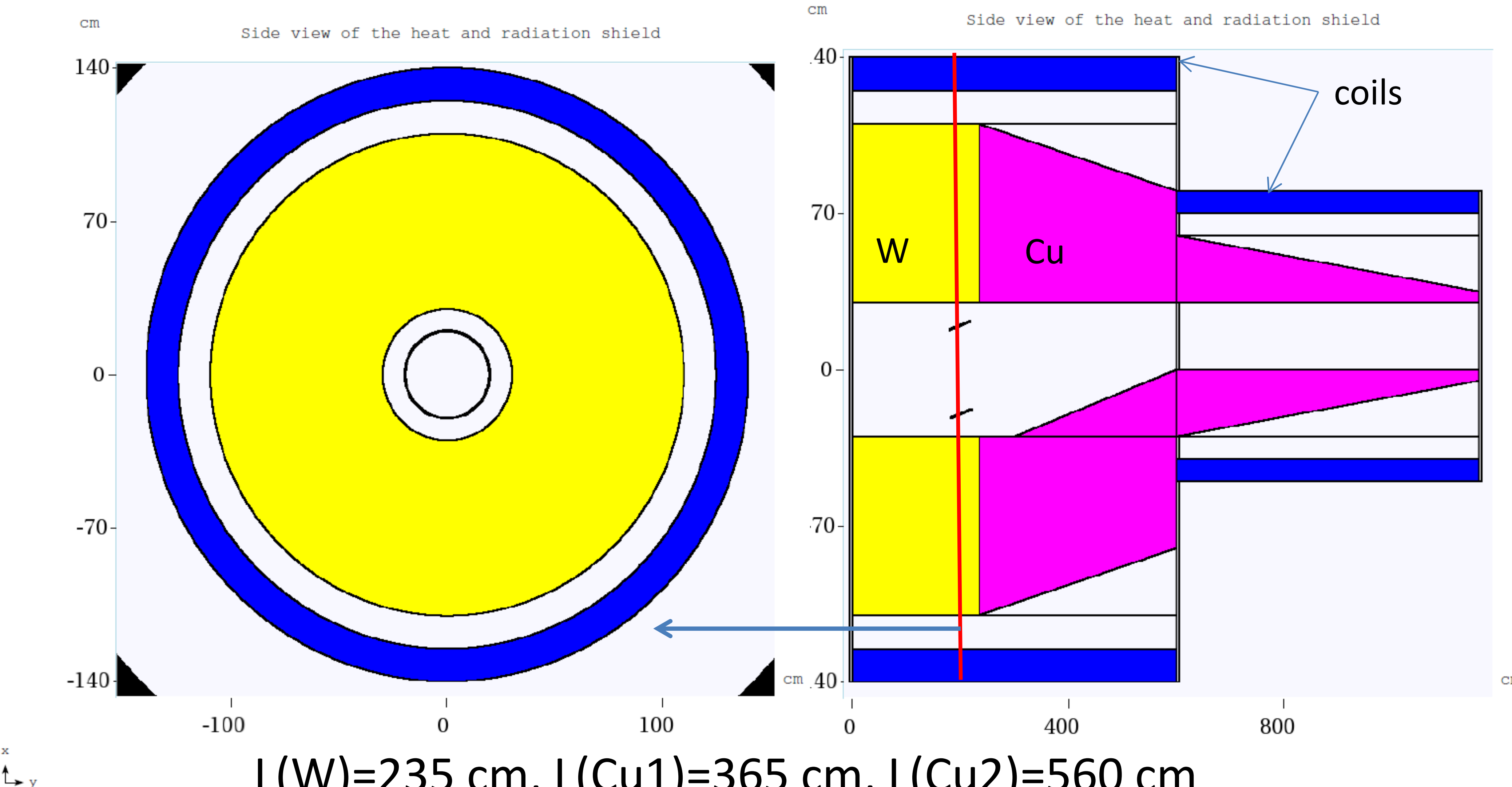


Radiation quantities at TS1

DPA=2.2E-6/yr, Power density= 0.5E-3 mW/g,
Absorbed dose = 1.1E4 Gy/yr,



Preliminary MARS model of Mu2e@PX heat and radiation shield. Shape optimization

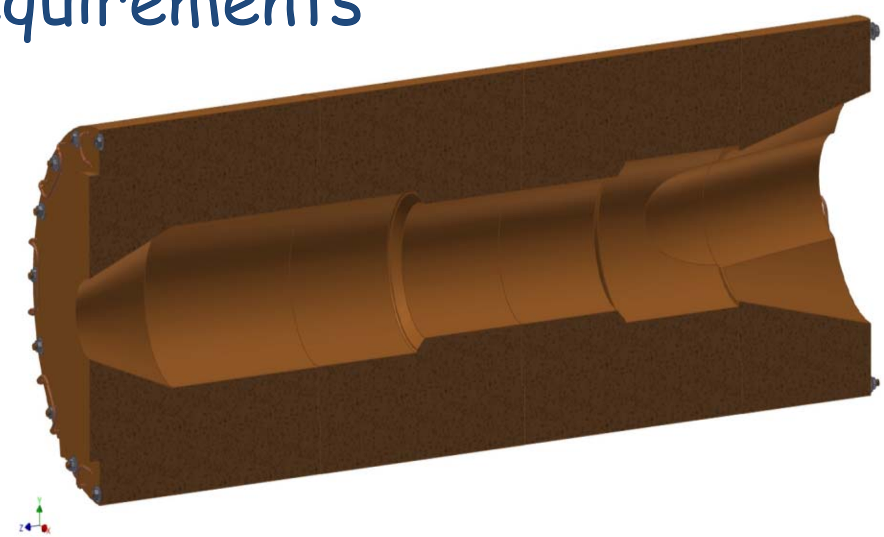


L(W)=235 cm, L(Cu1)=365 cm, L(Cu2)=560 cm

1 MW, C target: ~190 tonnes of W/130 tonnes of Cu

Conclusions

- Current Heat and Radiation Shield design based on thorough MARS15 simulations satisfies all the requirements for 1/3 of the nominal beam power
- An engineering design based on the model has been developed
- A model of Heat and Radiation Shield is also proposed for the case of nominal beam power, also satisfying all requirements



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