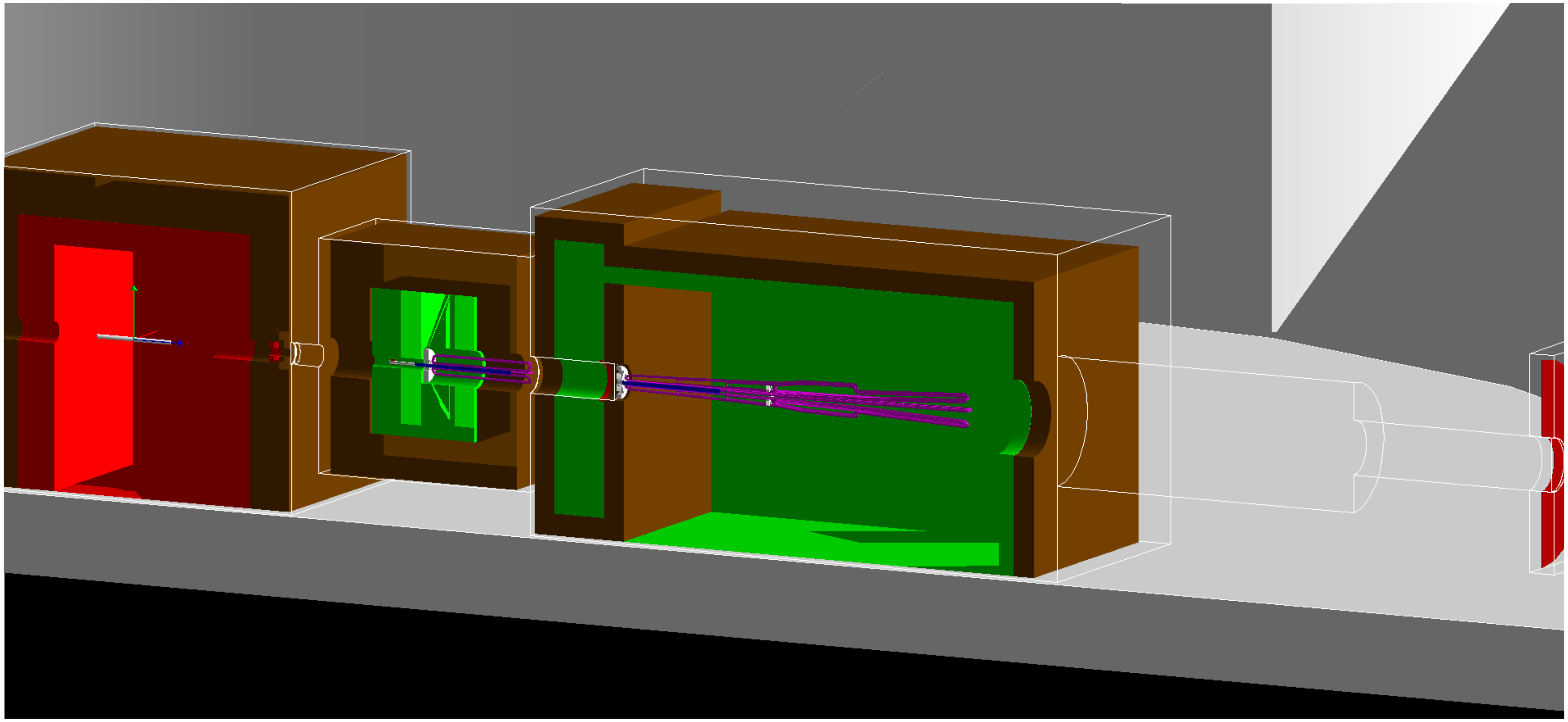
Proof of Concept Radiation Shielding Design



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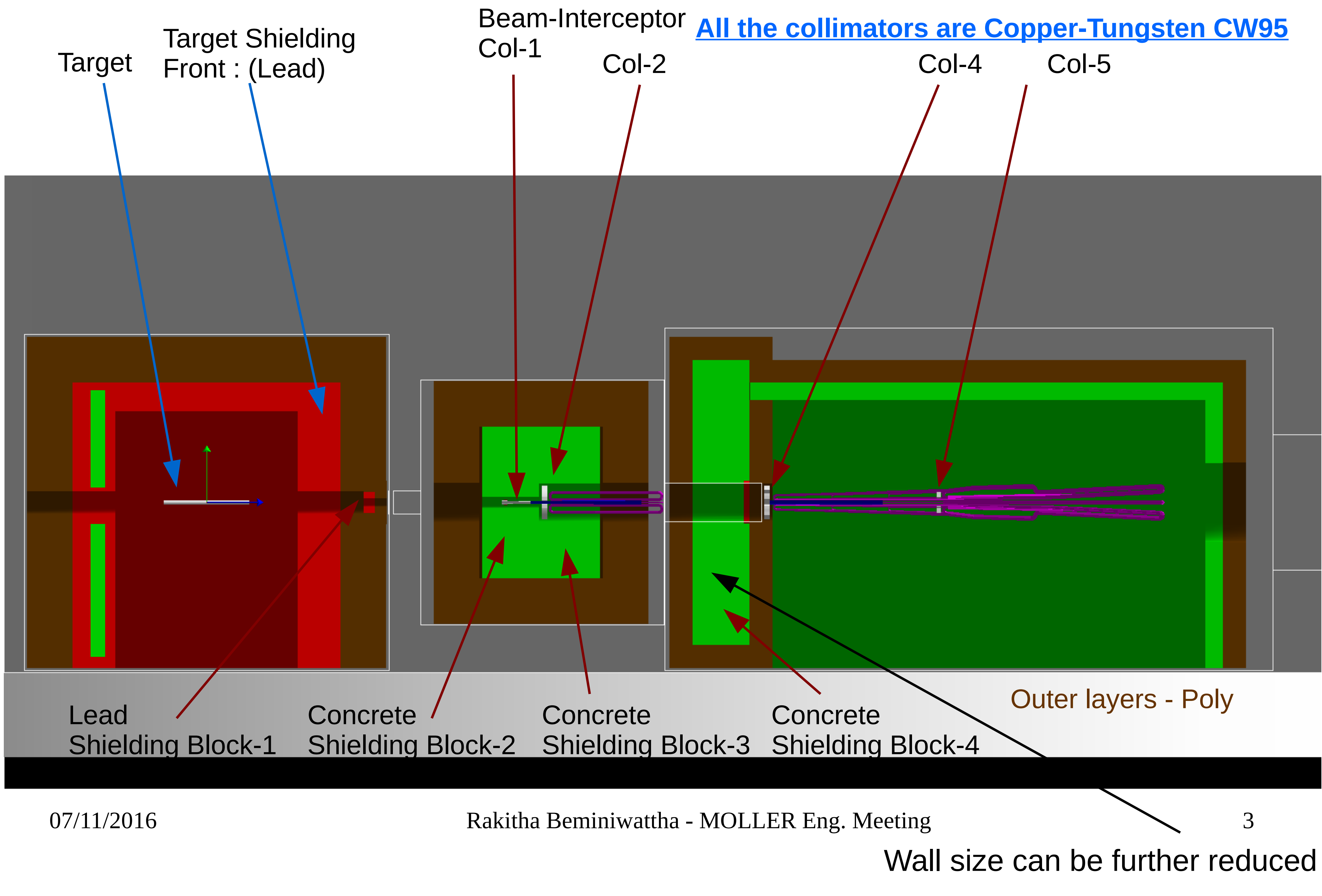
MOLLER Engineering Meeting July 2016

Shielding Design

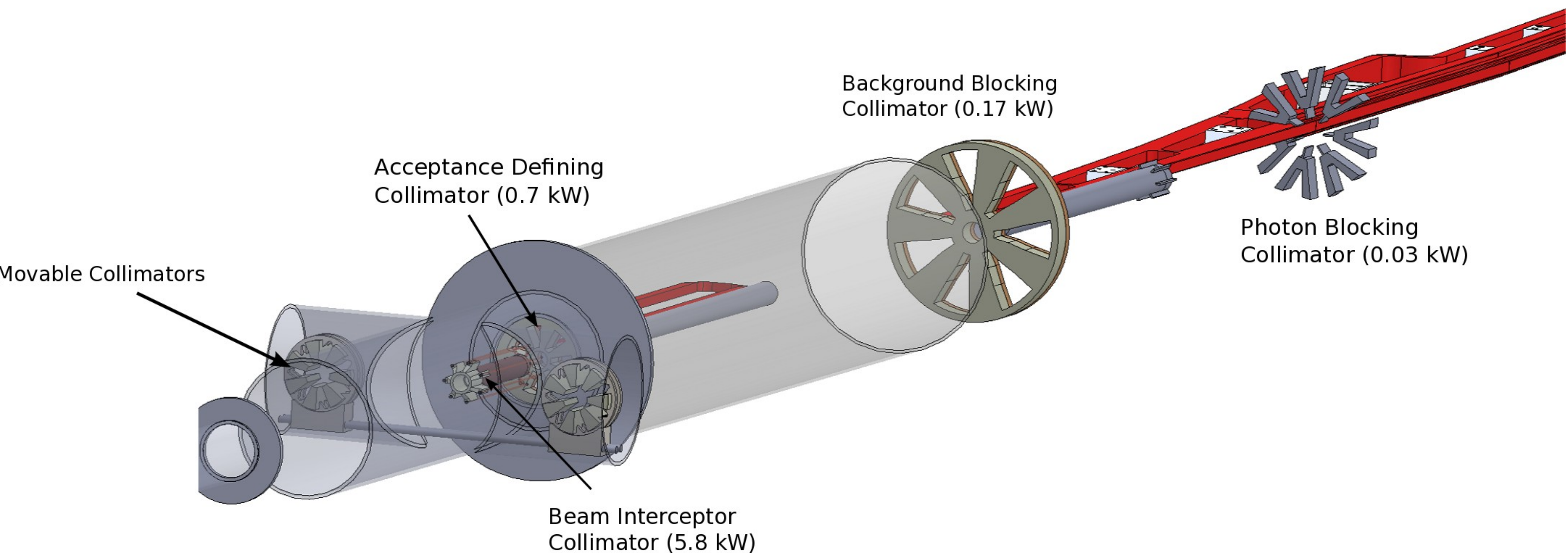
- Single collimator to intercept low angle scattered beam
  - To isolate neutron production
- Target shielding required a lead wall
  - To stop EM power from the target
- Concrete and Tungsten for high energy neutrons
- Polythene for low energy neutrons (< 10 MeV)
- Goal of the shielding is to reduce the EM and neutron radiation into the hall A and reduce background at the detector region

Shielding Design



Collimation System

- Block two bounce photons to detectors
- Require radiation shielding
- Require precision alignment
- Require water cooling
- Two movable collimators for background and tracking studies



Beam-Interceptor Collimator : Power Deposit Comparison : CW95

Separate Collimators

Separate Col-1 and Col-3				
Collimator	Total (W)	e- (W)	e+ (W)	Gamma (W)
1	3238.5	2141.5	996.7	97.8
2	1757.5	1195.3	501.9	58.5
3	1985.4	1331.7	588.4	63.5
4	229.0	156.1	65.1	7.7
5	34.7	23.0	10.5	1.1

With Beam-Interceptor Collimator

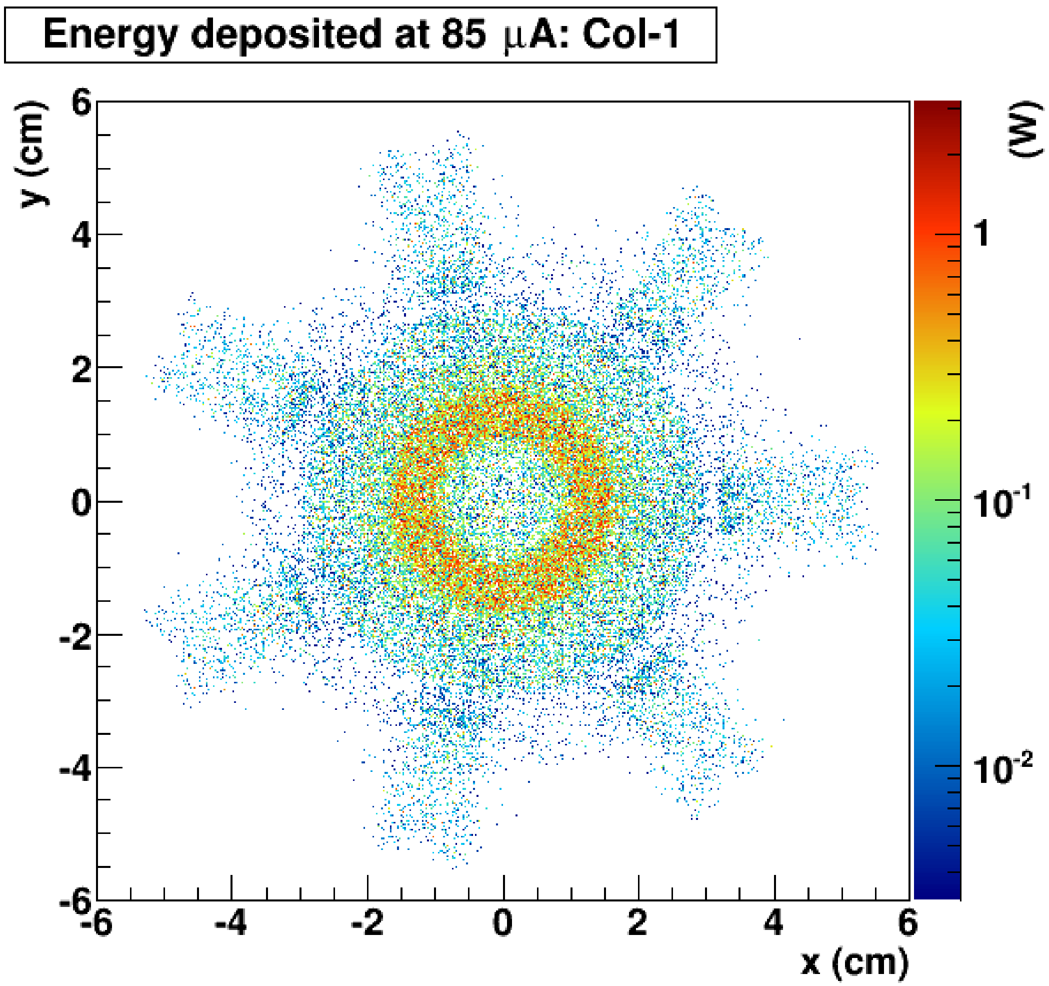
Col-1 with Fins				
Collimator	Total (W)	e- (W)	e+ (W)	Gamma (W)
1	5820.5	3836.4	1811.3	170.6
2	691.8	476.2	191.2	23.7
3	0.0	0.0	0.0	0.0
4	163.2	110.4	47.6	5.2
5	31.8	20.9	9.9	1.0
Fins Only	395.9	266.0	117.4	12.4

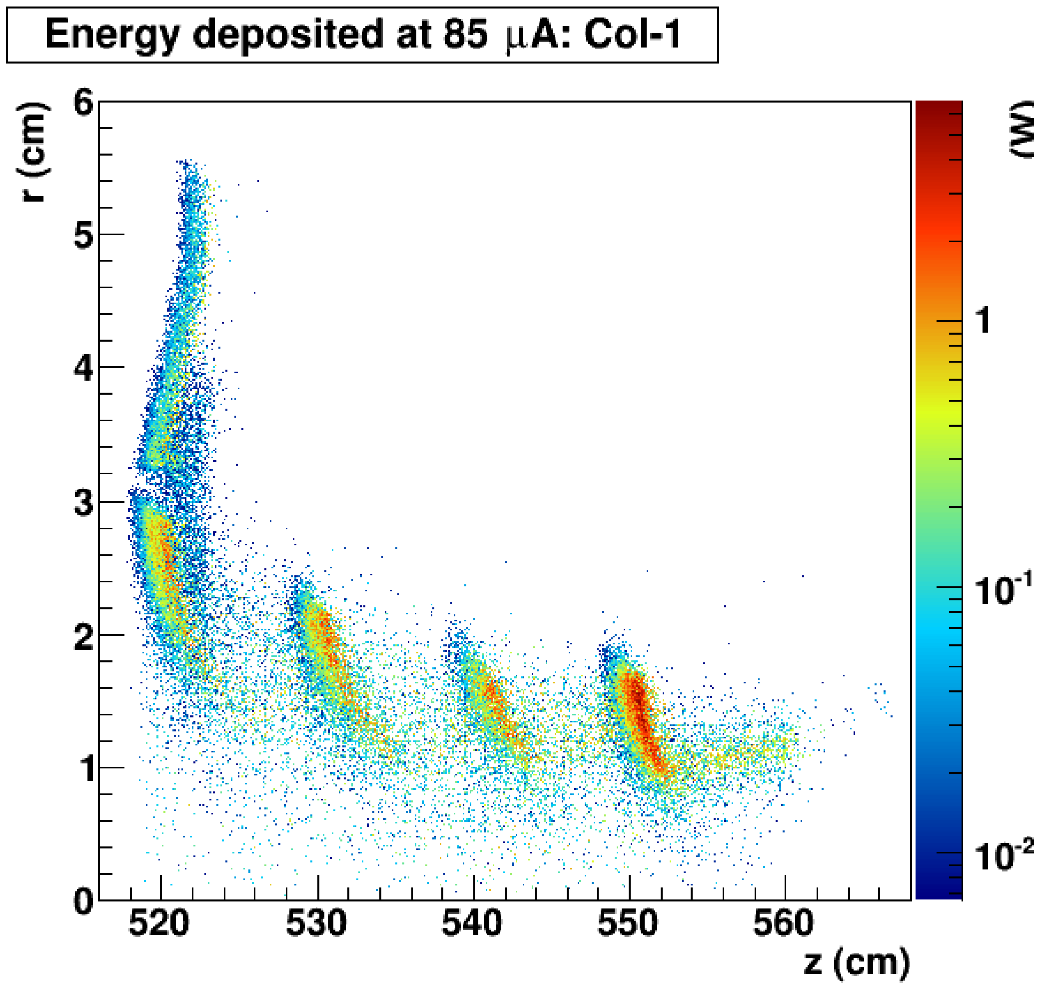
Col-1 Binned			
Index	Z bin (cm)	Edep (With no Fins)	Edep (With Fins)
1	0-5	210.7	201.7
2	5-10	743.3	1168.0
3	10-15	277.2	209.9
4	15-20	882.3	905.6
5	20-25	190.9	205.2
6	25-30	764.1	775.99
7	30-35	384.7	331.87
8	35-40	1781.0	1854.23
9	40-45	155.0	142.7
10	45-50	17.8	25.43

Collimators are made out of CW95 tungsten alloy

Total power deposited in all the Fins 400 W (57 W per Fin) at 85 uA

Power Deposit Map





Radiation to the Hall with Tungsten Beam-pipe

- At current state radiation levels are about PREX-II
- Only low energy neutrons are above the PREX-II limit!
  - Manageable with better poly-shielding
- Now time for engineering input

Radiation Power to Hall (top detector excluded)

		Lead tgt Sheld + Concrete + Shield Beampipe + CW95 + Lead Collar	PREX_I	PREX_II
Type	E range	**Power**	Power	Power
	(MeV)	**(W/uA)**	(W/uA)	(W/uA)
e±	E<10	**0.0004**	0.1663	0.0091
	10<E	**0.0585**	1.2880	0.0562
Photons	E<10	**0.0060**	0.7455	0.0763
	10<E	**0.0419**	2.0330	0.1070
Neutrons	E<10	**0.00002**	0.0023	0.0003
	10<E	**0.0006**	0.0039	0.0012

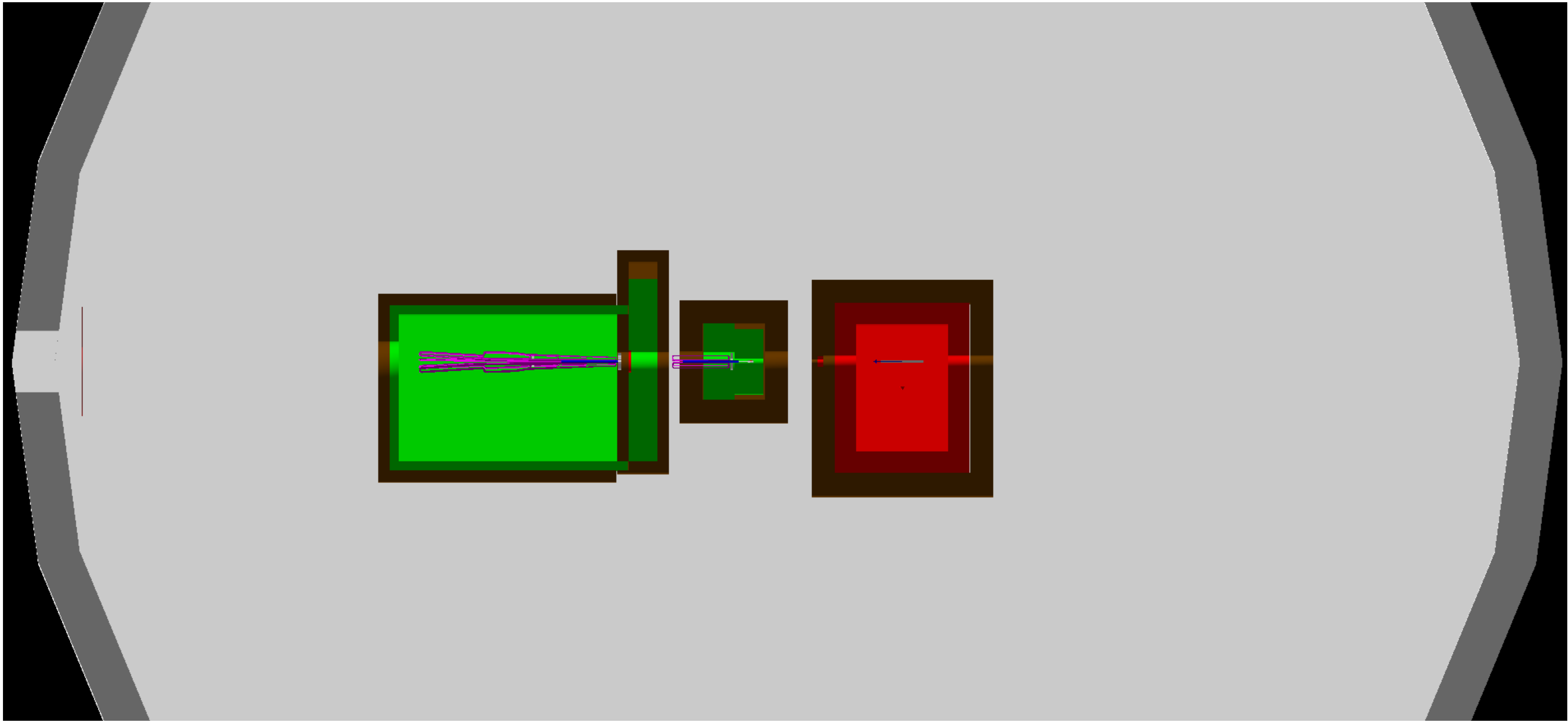
Note: Prex simulation numbers only from “Hall Detector”

Radiation Flux to Hall (top detector excluded)

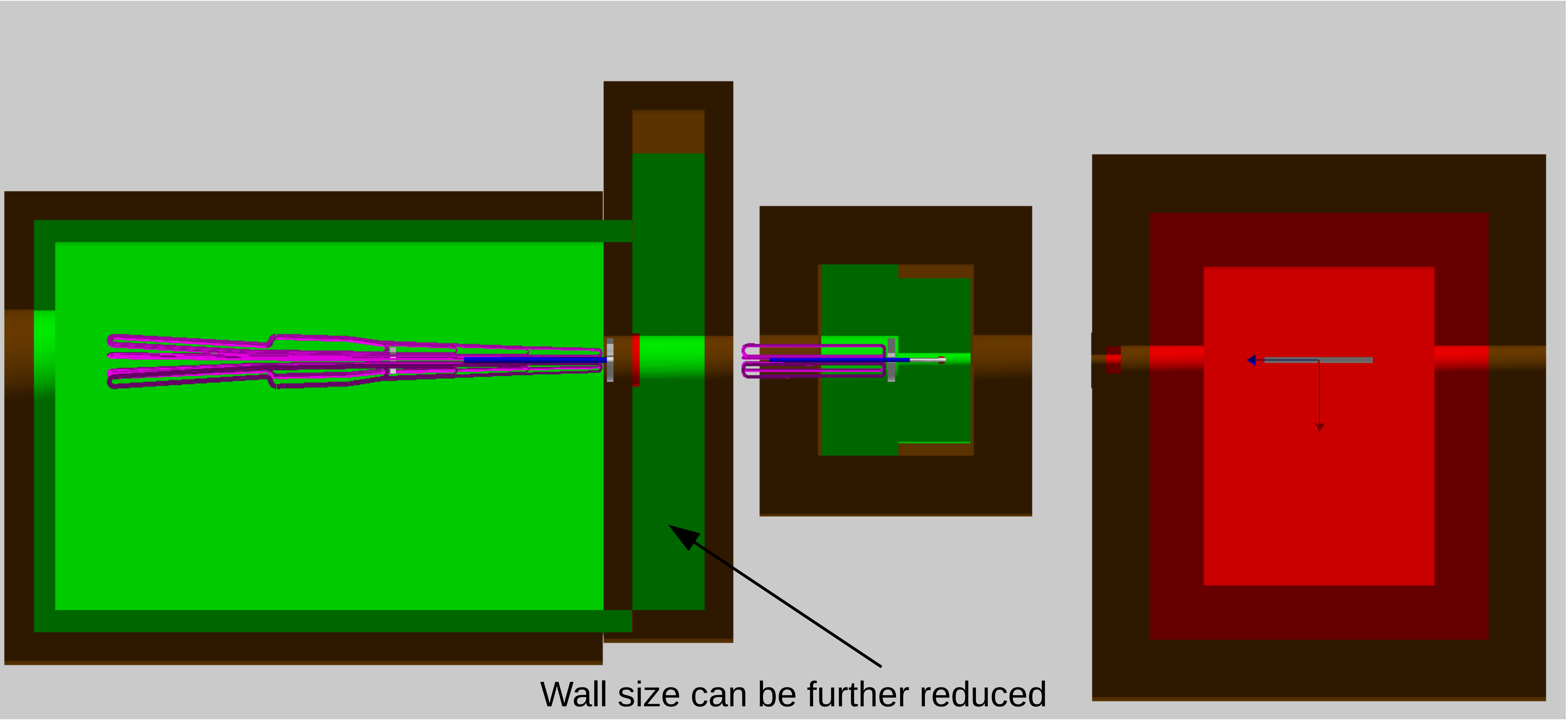
		Lead tgt Sheld + Concrete + Shield Beampipe + CW95 + Lead Collar	PREX_I	PREX_II
Type	E range	**Flux**	Flux	Flux
	(MeV)	**(Hz/uA)**	(Hz/uA)	(Hz/uA)
e±	E<10	**3.43E+09**	3.45E+11	2.05E+10
	10<E	**1.00E+09**	2.10E+11	9.42E+09
Photons	E<10	**6.29E+10**	5.49E+12	6.41E+11
	10<E	**4.55E+09**	3.43E+11	1.93E+10
Neutrons	E<10	**2.99E+09**	1.62E+10	1.79E+09
	10<E	**3.74E+07**	3.93E+08	1.34E+08

Note: Prex simulation numbers only from “Hall Detector”

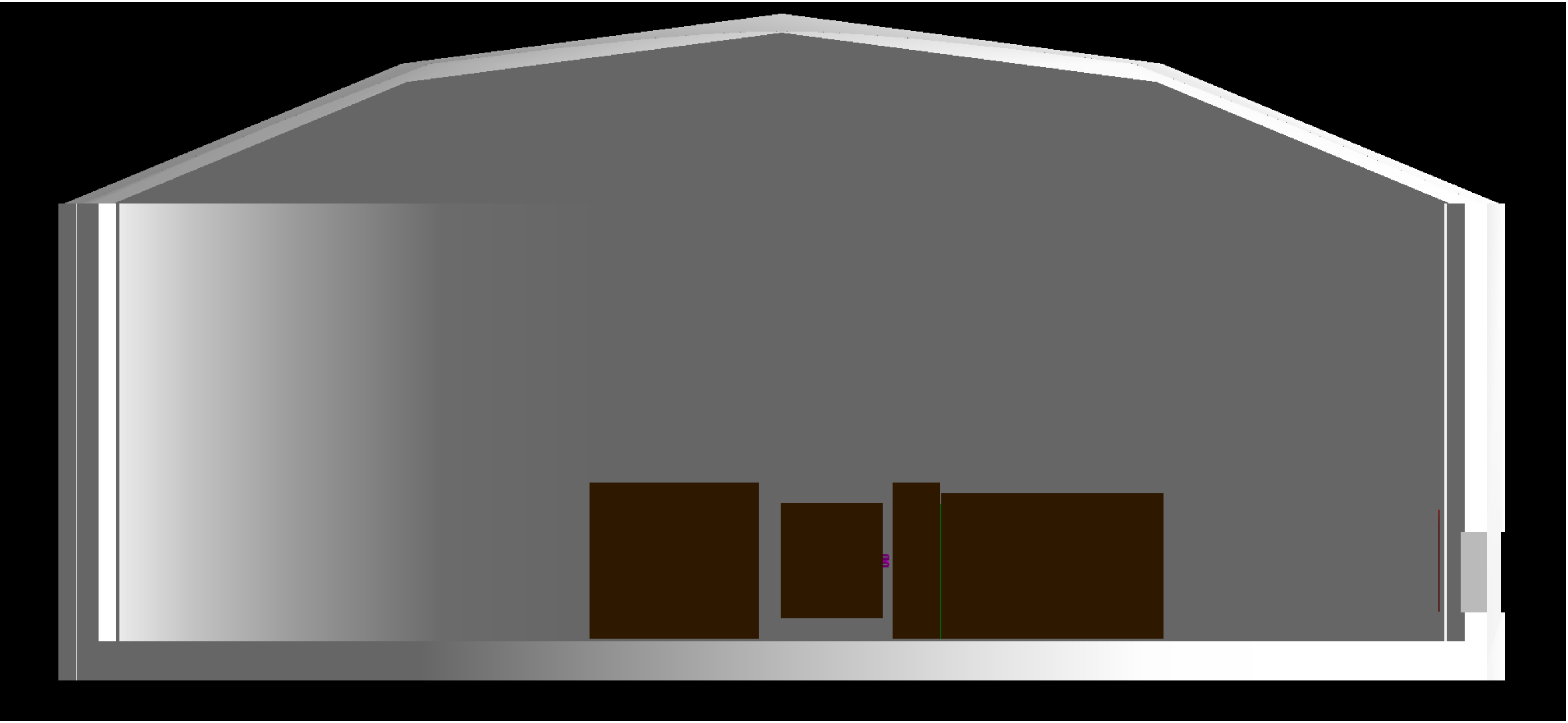
Shielding Design : Top View



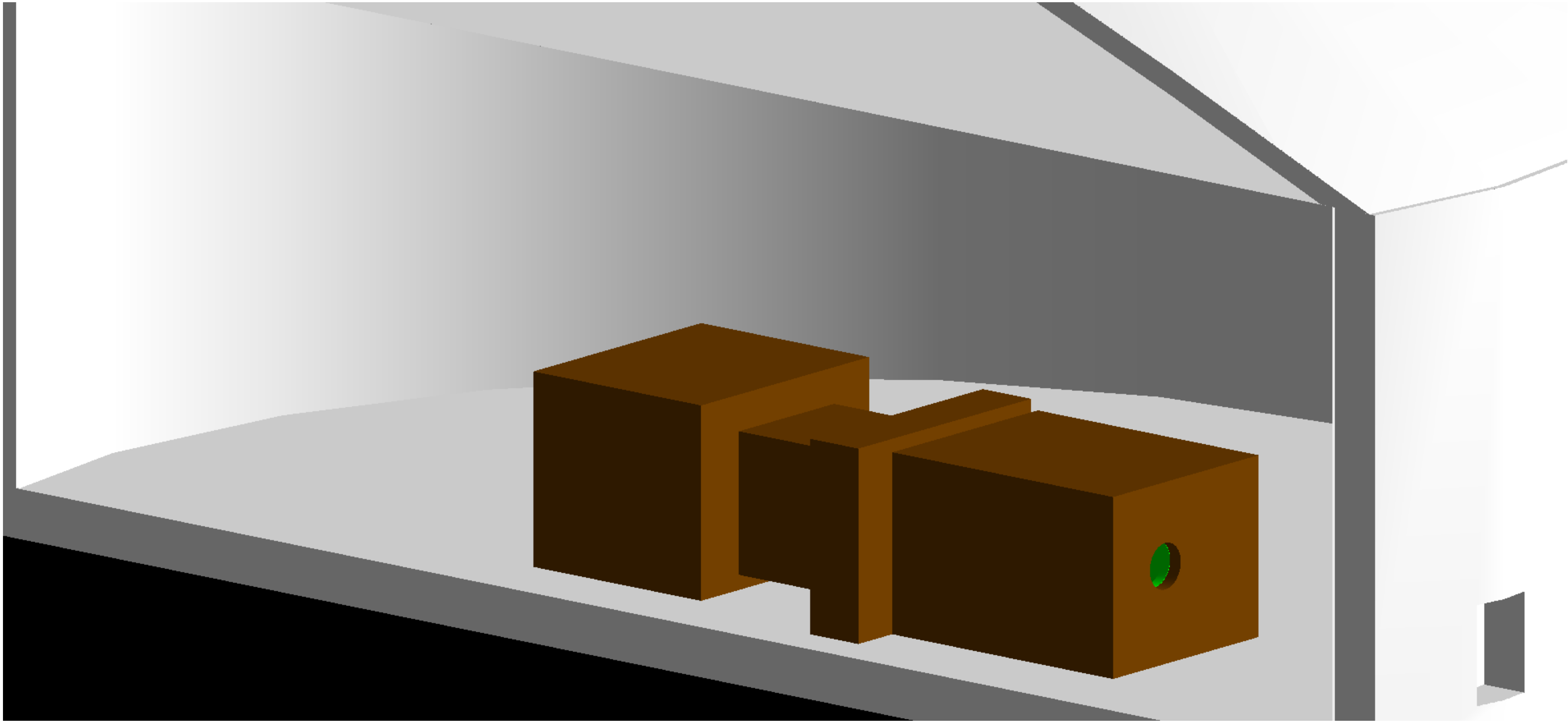
Shielding Design : Top View



Shielding Design : Side View



Shielding Design : Side View



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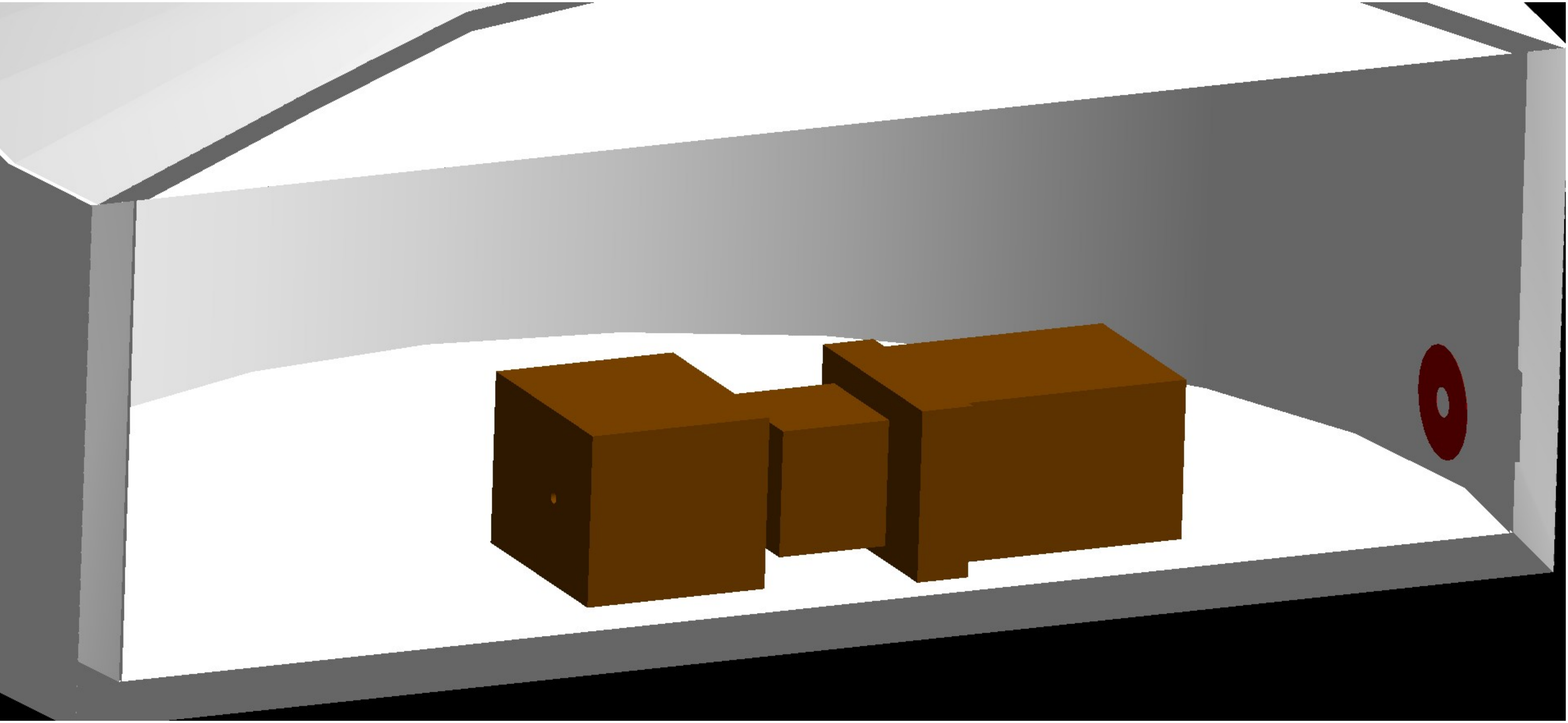

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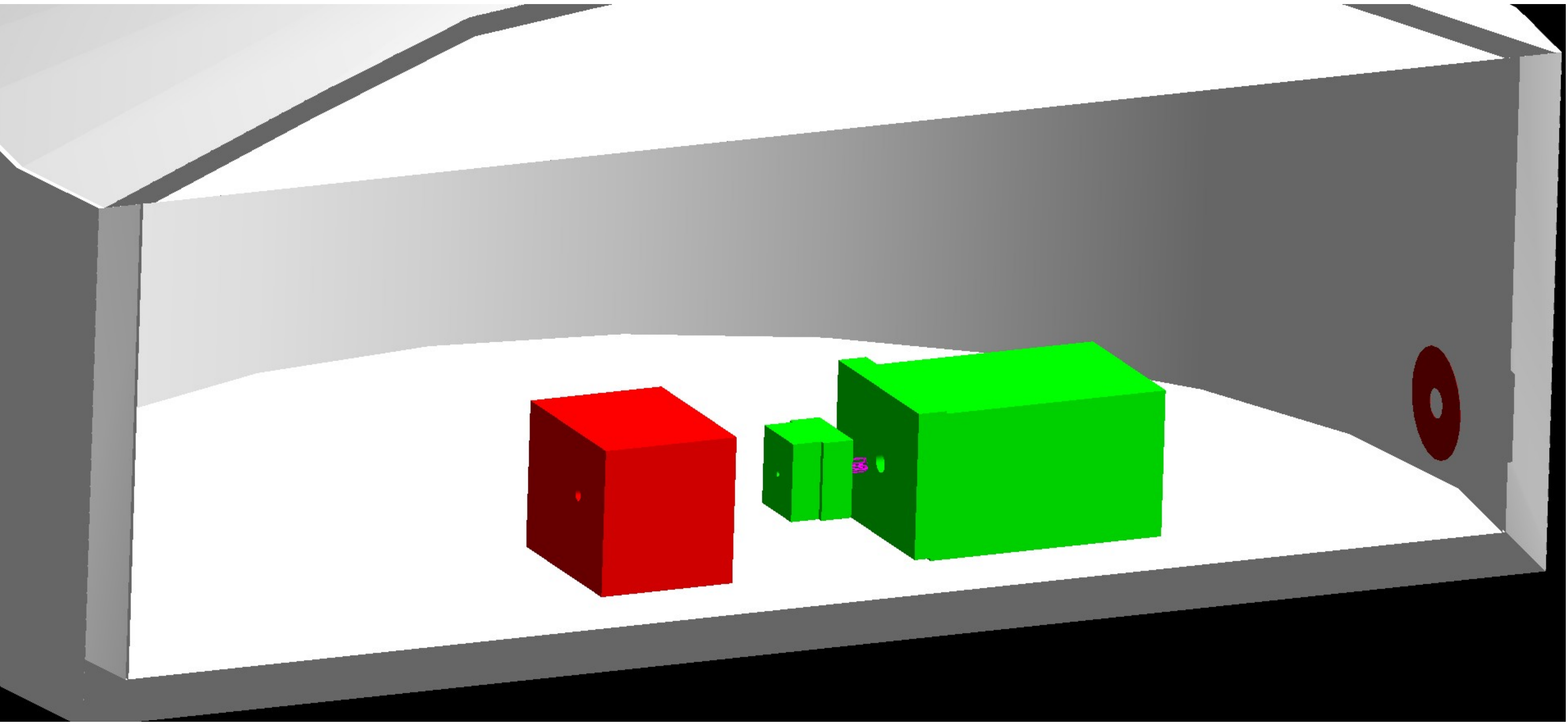
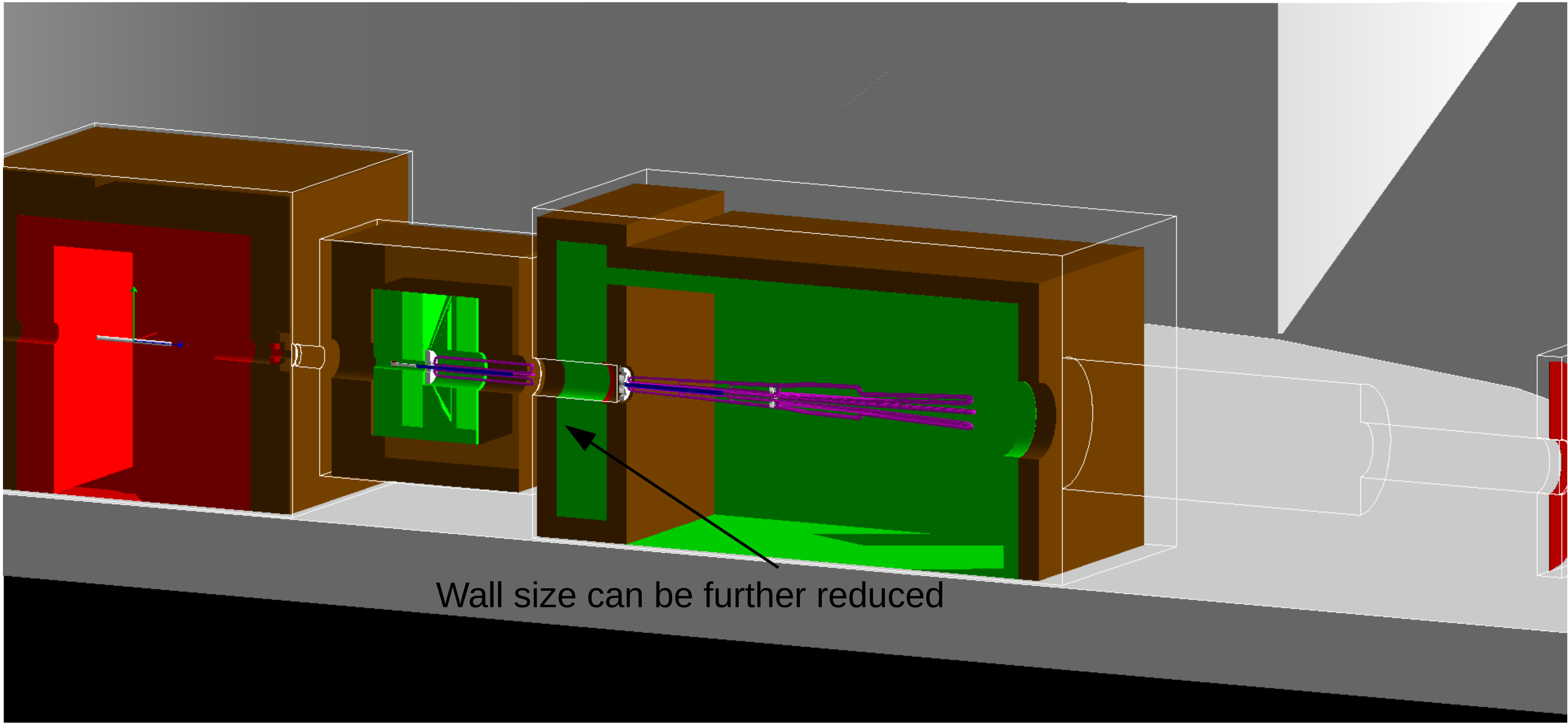


Shielding Design : Side View

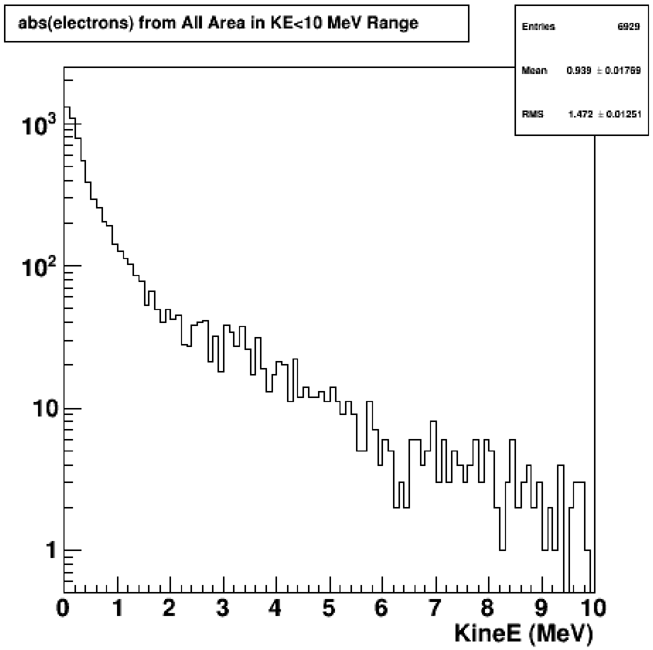


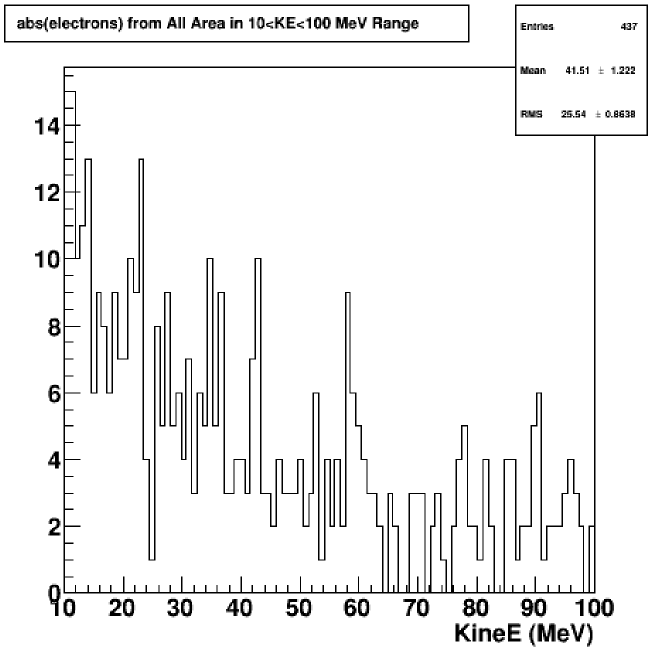
Summary

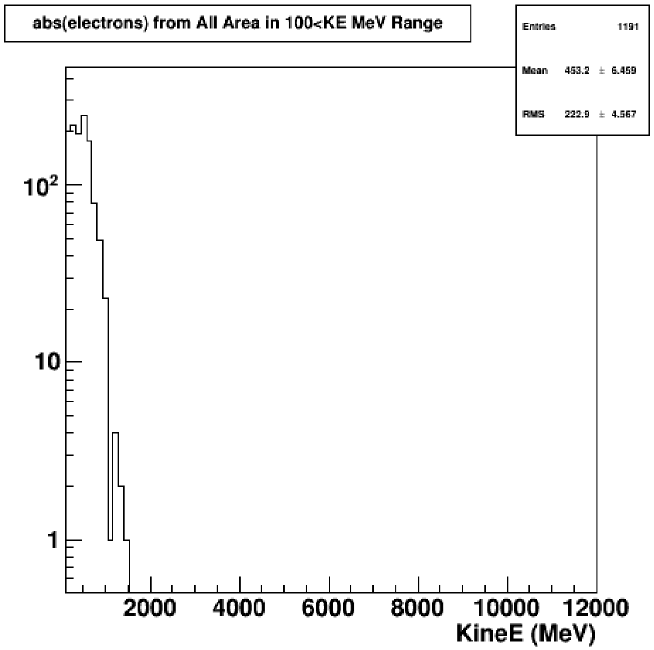
- Present design is a proof of concept that MOLLER shielding is achievable
  - Goal : To reach PREX-II radiation levels → **Done**
- Next steps in short term
  - Investigate major conflicts in the shielding design → Next talk
  - Feedback from Engineers

Supplementary

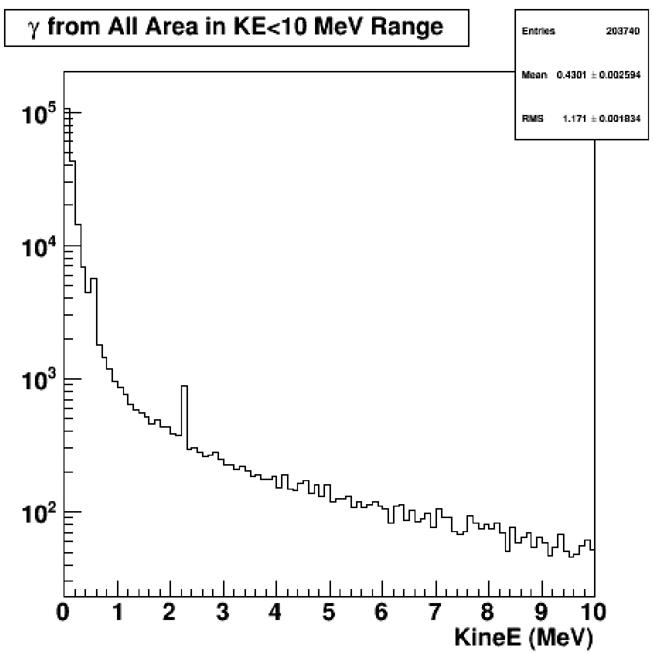
Hall Radiation Energy Distributions Electrons

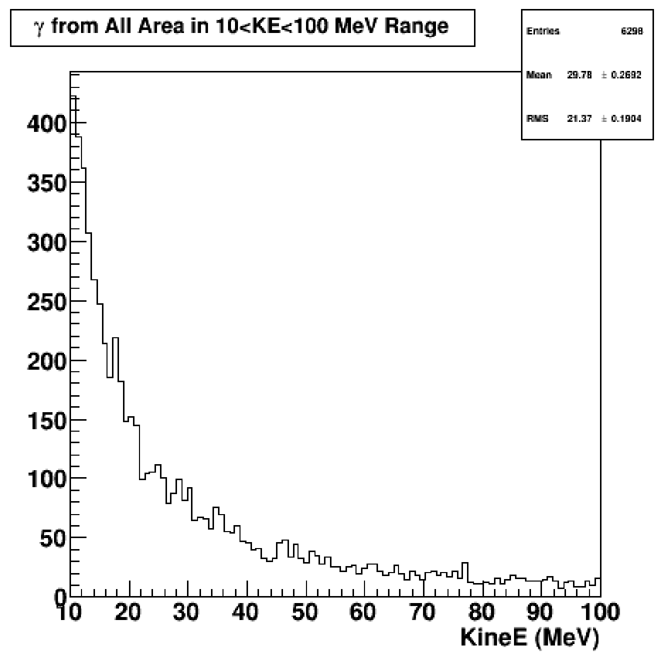


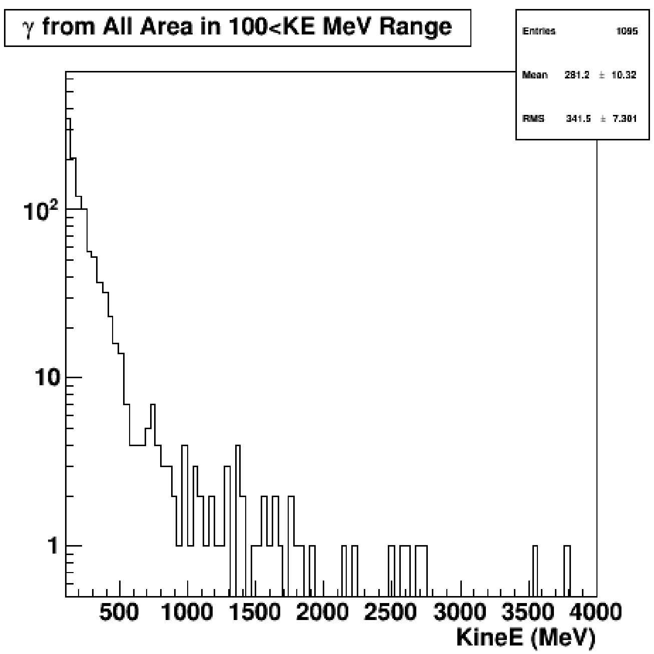




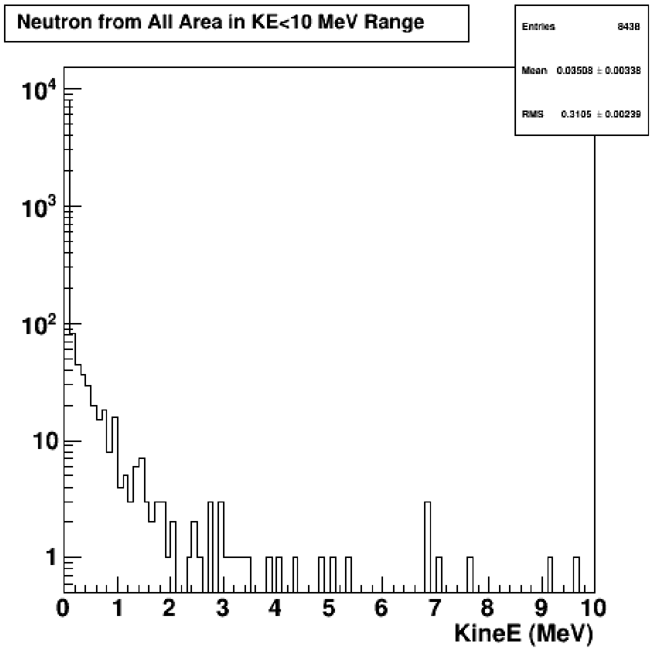
Hall Radiation Energy Distributions Photons

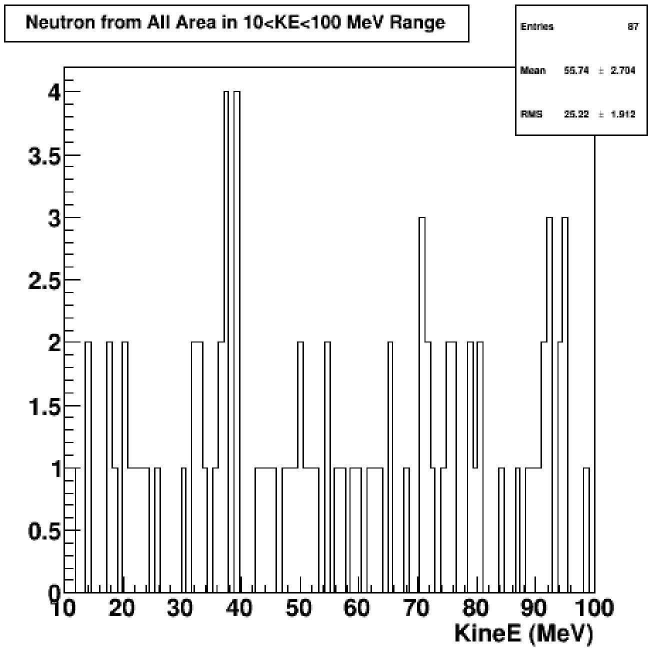


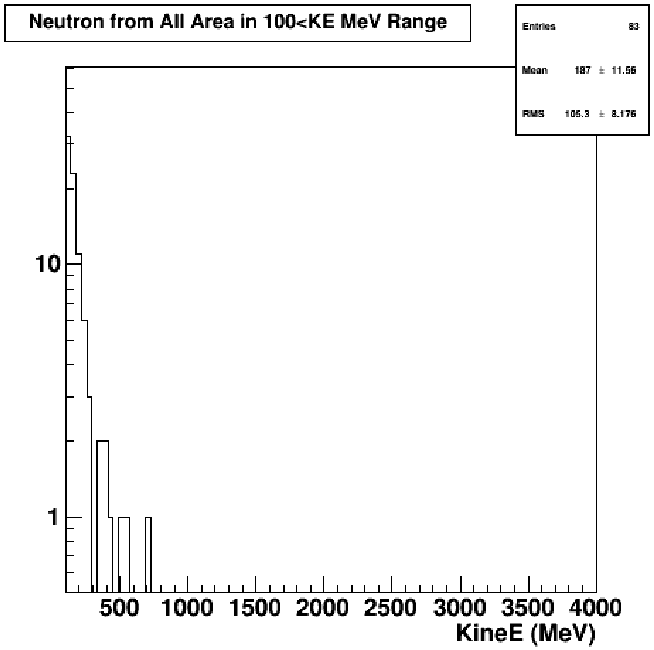




Hall Radiation Energy Distributions
Neutrons







Radiation to Hall by Vertex Region

Contribution to the Total Radiation Flux : Before								
Type	E range	ShTarget	ShBlock-1	ShBlock-2	ShBlock-3	ShBlock-4	Other	Total
	(MeV)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
e±	E<10	16.1	2.7	6.2	0.5	0.2	74.3	100.0
	10<E<100	32.6	2.0	1.8	0.4	0.3	62.9	100.0
	100<E	56.5	0.1	0.7	0.0	0.0	42.8	100.0
Photons	E<10	8.3	23.8	21.6	4.8	0.8	40.7	100.0
	10<E<100	29.7	10.6	11.3	1.9	5.8	40.6	100.0
	100<E	44.0	0.2	16.1	1.5	2.8	35.5	100.0
Neutrons	E<10	1.1	9.2	67.3	5.1	0.3	17.0	100.0
	10<E<100	27.7	15.8	6.4	0.7	0.7	48.6	100.0
	100<E	46.0	11.2	7.4	0.9	0.0	34.4	100.0

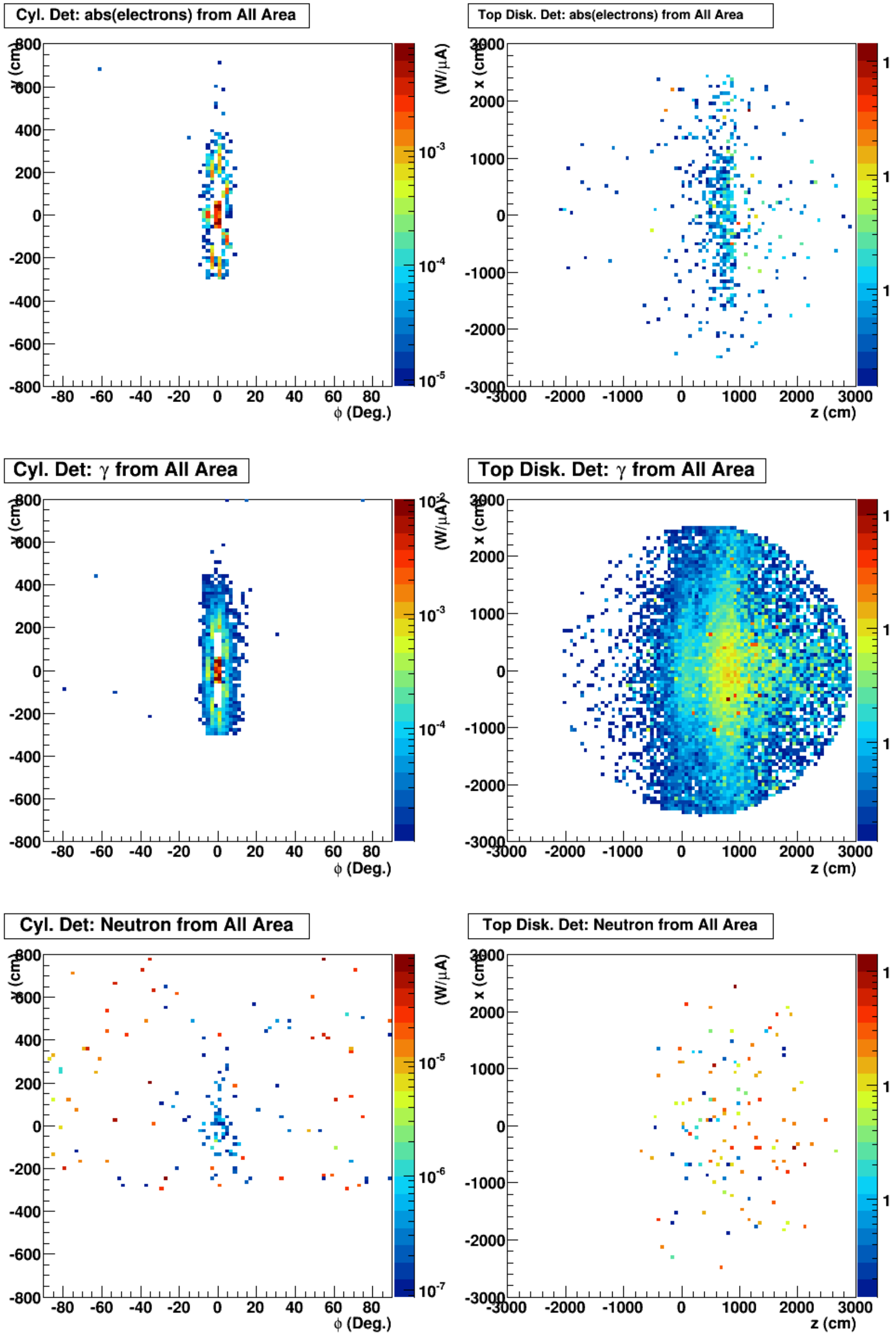
Contribution to the Total Radiation Flux : After								
Type	E range	ShTarget	ShBlock-1	ShBlock-2	ShBlock-3	ShBlock-4	Other	Total
	(MeV)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
e±	E<10	63.9	1.3	6.2	0.3	0.1	28.3	100.0
	10<E<100	31.1	0.0	2.5	0.2	0.0	66.1	100.0
	100<E	59.6	0.0	1.3	0.0	0.0	39.0	100.0
Photons	E<10	9.1	18.9	24.3	3.0	1.5	43.2	100.0
	10<E<100	21.8	2.8	13.2	2.1	7.9	52.2	100.0
	100<E	41.0	0.0	16.6	2.6	2.6	37.2	100.0
Neutrons	E<10	21.7	7.6	58.9	1.7	0.3	9.7	100.0
	10<E<100	5.7	10.3	10.3	4.6	0.0	69.0	100.0
	100<E	14.5	18.1	16.9	3.6	0.0	47.0	100.0

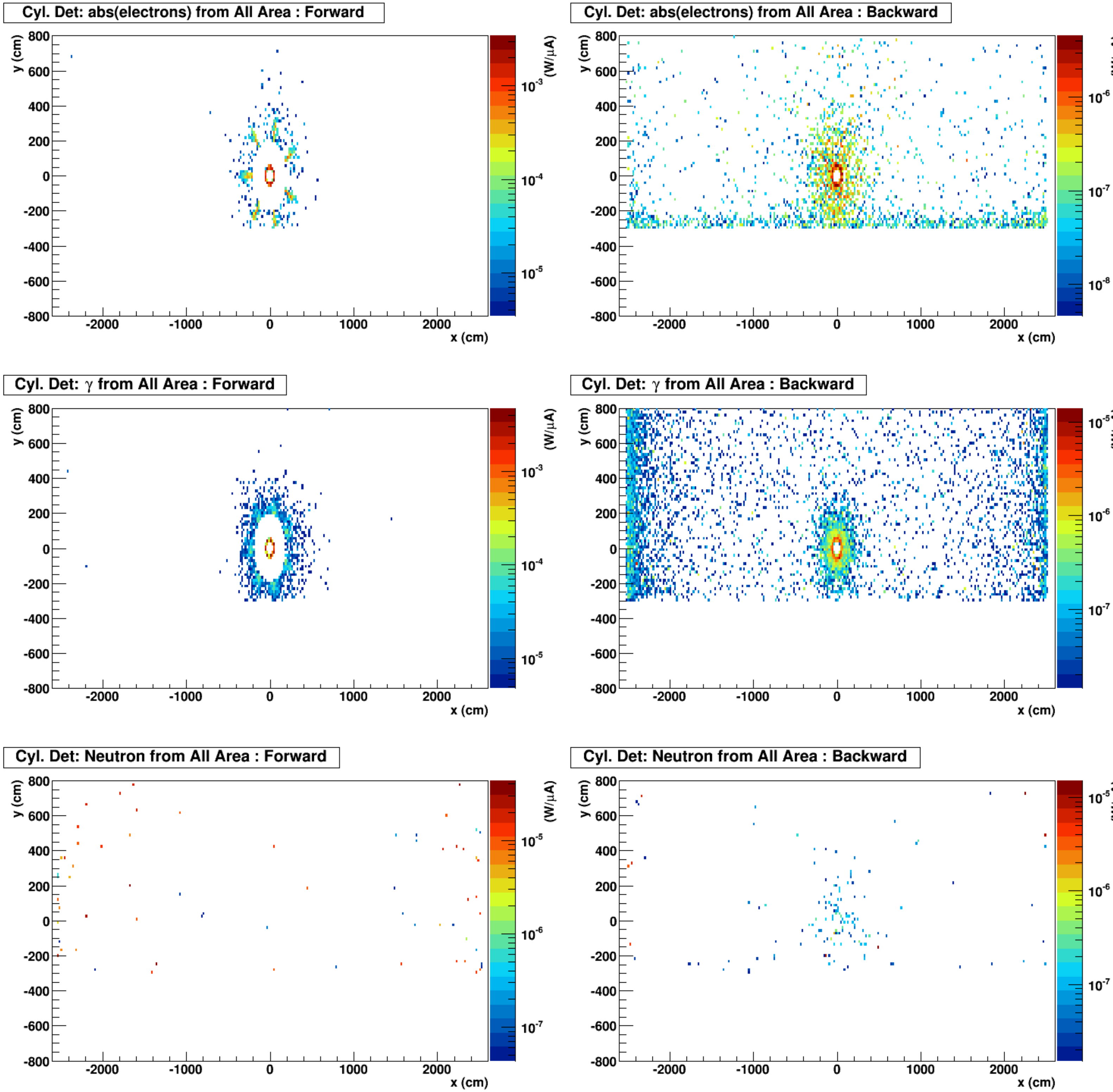
“Other” definition : All other vertices not in shielding blocks

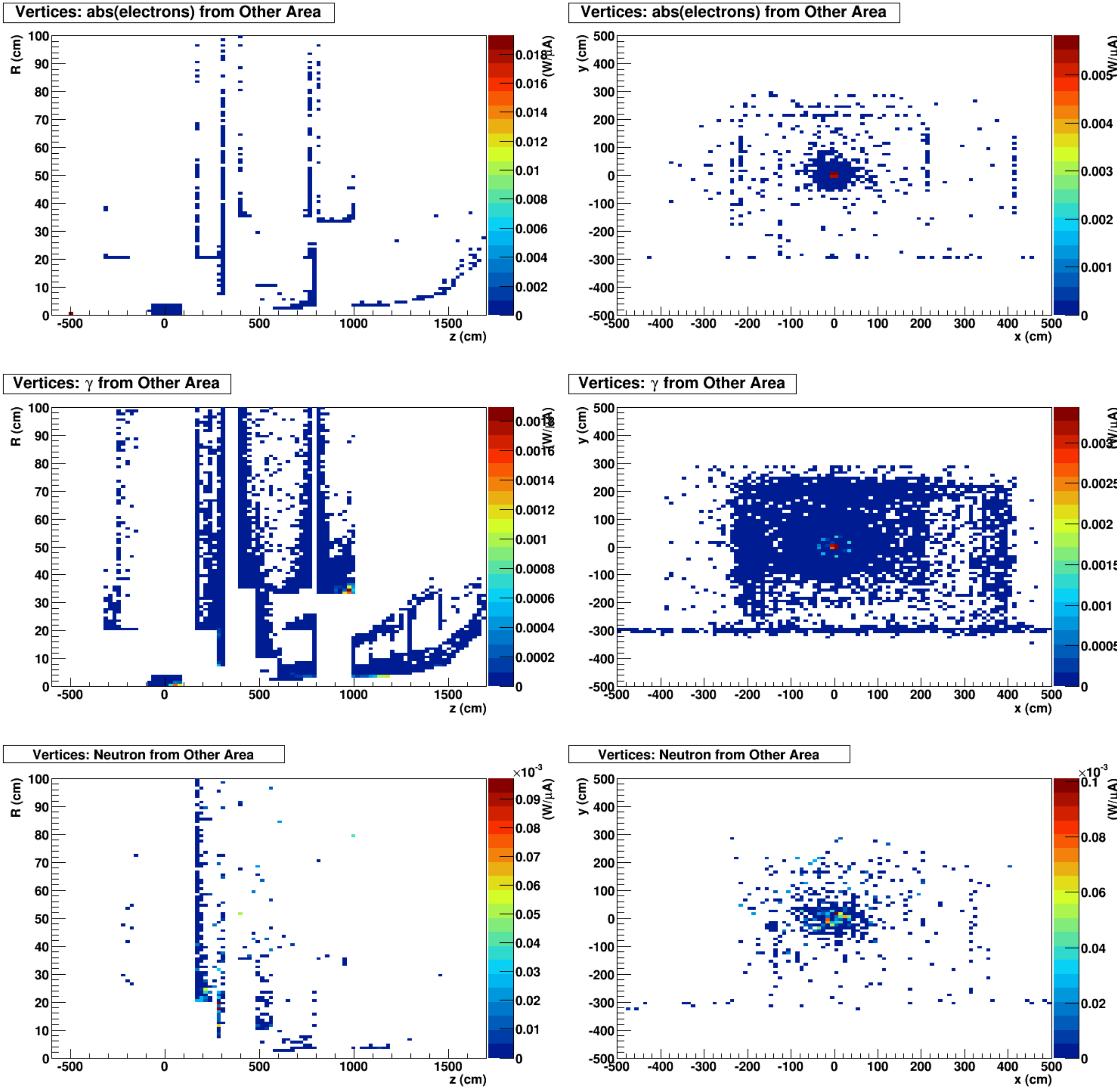
Radiation to Top of the Hall

Comparable amount of radiation leaks to top of the hall

Radiation Side vs. Top				
Type	E range (MeV)	Cylinder (Hz/uA)	Top (Hz/uA)	Total (Hz/uA)
e±	E<10	3.42E+09	9.07E+08	4.32E+09
	10<E<100	2.55E+08	1.81E+07	2.73E+08
	100<E	7.41E+08	2.50E+06	7.43E+08
Photons	E<10	6.54E+10	6.17E+10	1.27E+11
	10<E<100	3.75E+09	1.86E+08	3.93E+09
	100<E	6.78E+08	5.62E+06	6.83E+08
Neutrons	E<10	2.88E+09	2.39E+09	5.27E+09
	10<E<100	2.43E+07	3.00E+07	5.43E+07
	100<E	2.68E+07	2.50E+07	5.18E+07


Cyl. Det: abs(electrons) from All Area
y (cm)
ϕ (Deg.)
(W/μA)
Top Disk. Det: abs(electrons) from All Area
x (cm)
z (cm)
Cyl. Det: γ from All Area
y (cm)
ϕ (Deg.)
(W/μA)
Top Disk. Det: γ from All Area
x (cm)
z (cm)
Cyl. Det: Neutron from All Area
y (cm)
ϕ (Deg.)
(W/μA)
Top Disk. Det: Neutron from All Area
x (cm)
z (cm)


Cyl. Det: abs(electrons) from All Area : Forward
Cyl. Det: abs(electrons) from All Area : Backward
Cyl. Det: γ from All Area : Forward
Cyl. Det: γ from All Area : Backward
Cyl. Det: Neutron from All Area : Forward
Cyl. Det: Neutron from All Area : Backward
y (cm)
x (cm)
(W/μA)


Vertices: abs(electrons) from Other Area
R (cm)
z (cm)
(W/μA)
Vertices: abs(electrons) from Other Area
y (cm)
x (cm)
(W/μA)
Vertices: γ from Other Area
R (cm)
z (cm)
(W/μA)
Vertices: γ from Other Area
y (cm)
x (cm)
(W/μA)
Vertices: Neutron from Other Area
R (cm)
z (cm)
×10^-3
(W/μA)
Vertices: Neutron from Other Area
y (cm)
x (cm)
×10^-3
(W/μA)

MIDWEST
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Tungsten Alloy Specifications

Material *	17 gm/cc 90% W 6% Ni 4% Cu	17 gm/cc 90% W 7% Ni 3% Fe	17.5 gm/cc 92.5% W 5.25% Ni 2.25% Fe	18 gm/cc 95% W 3.5% Ni 1.5% Cu	18 gm/cc 95% W 3.5% Ni 1.5 Fe	18.5 gm/cc 97% W 2.1% Ni 0.9% Fe
Density; lbs/in^3	0.614	0.614	0.632	0.65	0.65	0.668
Mil. Spec. T-21014 D	Class 1	Class 1	Class 2	Class 3	Class 3	Class 4
ASTM-B-459-67	Grade 1 Type II && III	Grade 1 Type II && III	Grade 2 Type II && III	Grade 3 Type II && III	Grade 3 Type II && III	Grade 4 Type II && III
Hardness; Rockwell C	24	25	26	27	27	28
Ultimate Tensile Strength; PSI	110,000	120,000	114,000	110,000	120,000	123,000
Yield Strength, .2% Offset; PSI	80,000	88,000	84,000	85,000	90,000	85,000
Elongation, % in 1"	6	10	7	7	7	5
Proportional Elastic Limit; PSI	45,000	52,000	46,000	45,000	44,000	45,000
Modulus of Elasticity; PSI	40×10^6	45×10^6	47×10^6	45×10^6	50×10^6	53×10^6
Coefficient of Thermal Expansion (x 10^{-6} 1°C 20°-400°C)	5.4	4.61	4.62	4.43	4.6	4.5
Thermal Conductivity; CGS Units	0.23	0.18	0.2	0.33	0.26	0.3
Electrical Conductivity; %IACS	14	10	13	16	13	17
Magnetic Properties	NIL	Slightly Magnetic	Slightly Magnetic	NIL	Slightly Magnetic	Slightly Magnetic

Tungsten vs. CW95

```
Material:     CW95    density: 18.000 g/cm3   RadL:   3.848 mm   Nucl.Int.Length:  10.804 cm   Imean: 692.470 eV
  --->  Element: Tungsten ( )   Z = 74.0   N = 183.8   A = 183.85 g/mole
        --->  Isotope:   180   Z = 74   N = 180   A = 179.95 g/mole   abundance:   0.12 %
        --->  Isotope:   182   Z = 74   N = 182   A = 181.95 g/mole   abundance:  26.50 %
        --->  Isotope:   183   Z = 74   N = 183   A = 182.95 g/mole   abundance:  14.31 %
        --->  Isotope:   184   Z = 74   N = 184   A = 183.95 g/mole   abundance:  30.64 %
        --->  Isotope:   186   Z = 74   N = 186   A = 185.95 g/mole   abundance:  28.43 %
         ElmMassFraction:  95.00 %  ElmAbundance  86.13 %

  --->  Element: Copper ( )   Z = 29.0   N =  63.5   A =  63.54 g/mole
        --->  Isotope:    63   Z = 29   N =  63   A =  62.93 g/mole   abundance:  69.17 %
        --->  Isotope:    65   Z = 29   N =  65   A =  64.93 g/mole   abundance:  30.83 %
         ElmMassFraction:   1.50 %  ElmAbundance   3.93 %

  --->  Element: Nickel (Ni)   Z = 28.0   N =  58.8   A =  58.70 g/mole
        --->  Isotope:  Ni58   Z = 28   N =  58   A =  57.94 g/mole   abundance:  68.08 %
        --->  Isotope:  Ni60   Z = 28   N =  60   A =  59.93 g/mole   abundance:  26.22 %
        --->  Isotope:  Ni61   Z = 28   N =  61   A =  60.93 g/mole   abundance:   1.14 %
        --->  Isotope:  Ni62   Z = 28   N =  62   A =  61.93 g/mole   abundance:   3.63 %
        --->  Isotope:  Ni64   Z = 28   N =  64   A =  63.93 g/mole   abundance:   0.93 %
         ElmMassFraction:   3.50 %  ElmAbundance   9.94 %
```

```
Material:     G4_W    density: 19.300 g/cm3   RadL:   3.504 mm   Nucl.Int.Length:  10.306 cm   Imean: 727.000 eV
  --->  Element: W (W)   Z = 74.0   N = 183.9   A = 183.84 g/mole
        --->  Isotope:  W180   Z = 74   N = 180   A = 179.95 g/mole   abundance:   0.12 %
        --->  Isotope:  W182   Z = 74   N = 182   A = 181.95 g/mole   abundance:  26.50 %
        --->  Isotope:  W183   Z = 74   N = 183   A = 182.95 g/mole   abundance:  14.31 %
        --->  Isotope:  W184   Z = 74   N = 184   A = 183.95 g/mole   abundance:  30.64 %
        --->  Isotope:  W186   Z = 74   N = 186   A = 185.95 g/mole   abundance:  28.43 %
         ElmMassFraction: 100.00 %  ElmAbundance 100.00 %
```