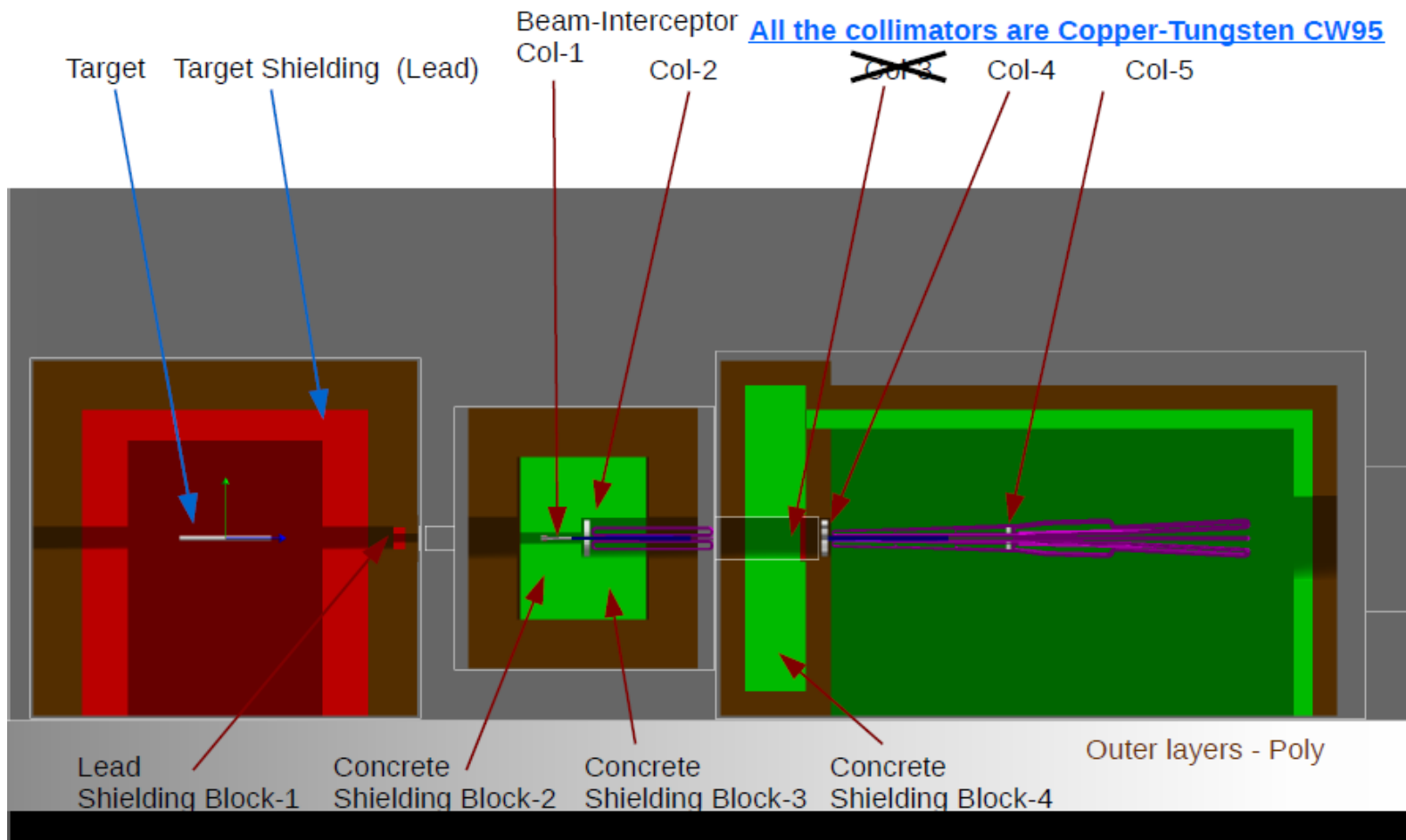


# MOLLER Radiation Studies Update – 2/14/2017

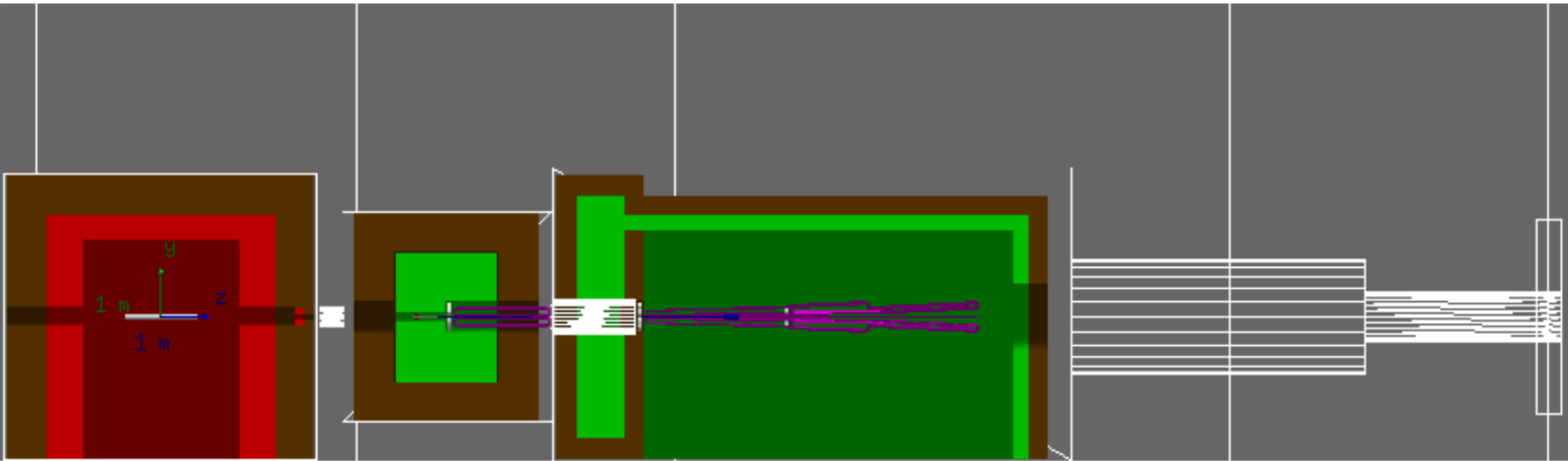
MOLLER Magnet Meeting  
Cameron Clarke

# Simulation first steps

We can pretty accurately reproduce Rakitha's original work



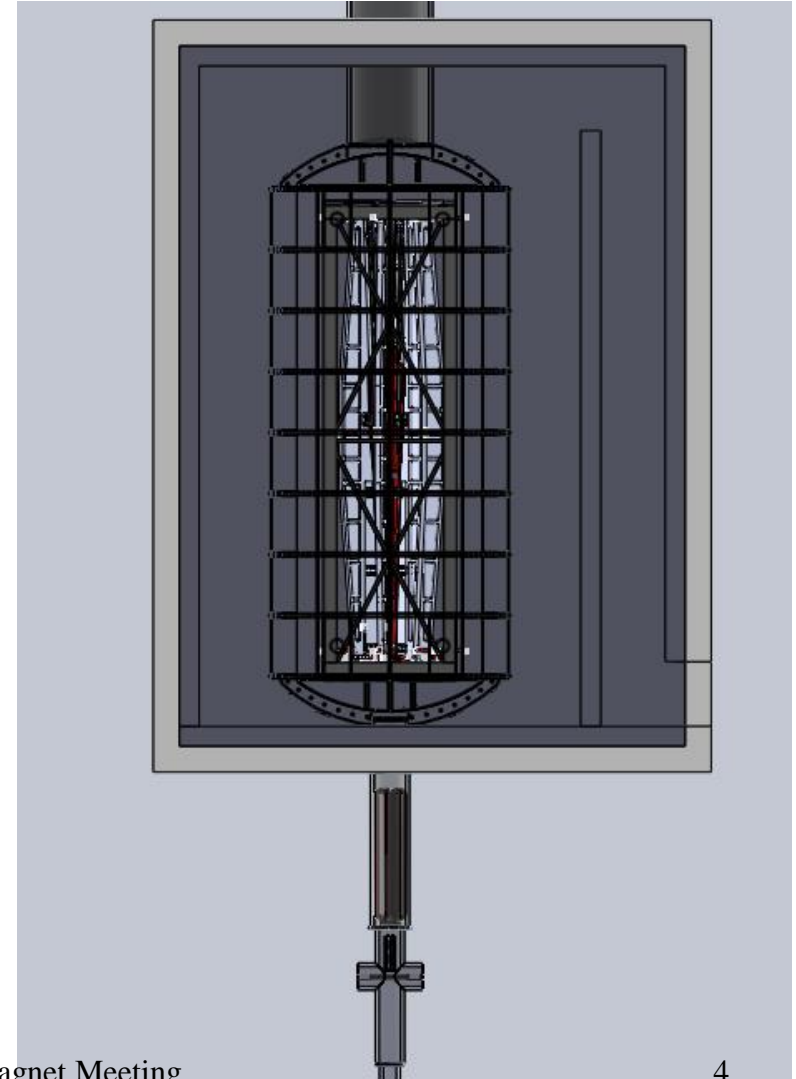
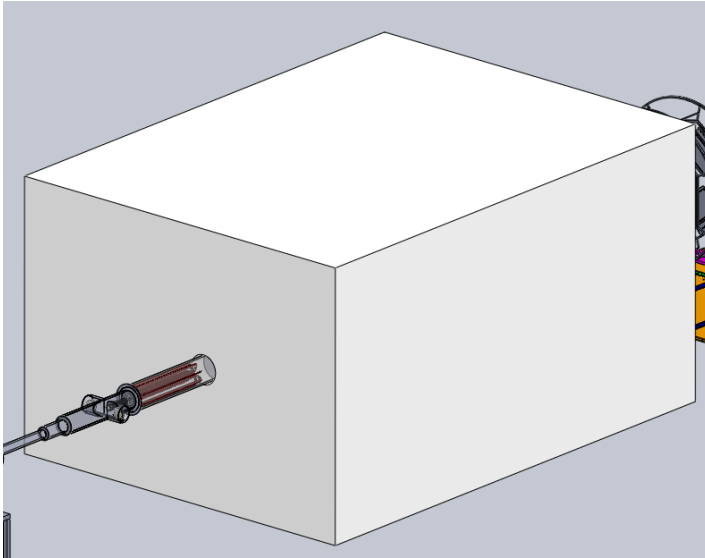
# Rakitha's original shielding implementation



What I see in Remoll:

Shielding in the hall surrounds hotspots ✓

# CAD of idealized shielding



It is a large concrete block with a large poly block surrounding it, which is very expensive and needs to be reduced to save money.

I am able to faithfully reproduce Rakitha's Geant 4 Remoll simulation results (within ~ 20 % for 1M events) for this configuration.

Rakitha's Numbers

| Power (W/microAmp) |               |         |
|--------------------|---------------|---------|
| Type               | E Range (MeV) | Side    |
| abs(electr         | E<10          | 0.0004  |
|                    | 10<E          | 0.0585  |
| Photons            | E<10          | 0.006   |
|                    | 10<E          | 0.0419  |
| Neutrons           | E<10          | 0.00002 |
|                    | 10<E          | 0.0006  |

Checking Rakitha's numbers

| Power (W/microAmp) |               |          |
|--------------------|---------------|----------|
| Type               | E Range (MeV) | Side     |
| abs(electr         | E<10          | 0.000585 |
|                    | 10<E          | 0.057668 |
| Photons            | E<10          | 0.008509 |
|                    | 10<E          | 0.056970 |
| Neutrons           | E<10          | 0.000018 |
|                    | 10<E          | 0.001345 |

PREX-II's Numbers

| Power (W/microAmp) |           |        |
|--------------------|-----------|--------|
| Type               | Range (Me | Top    |
| abs(electr         | E<10      | 0.0091 |
|                    | 10<E      | 0.0562 |
| Photons            | E<10      | 0.0763 |
|                    | 10<E      | 0.1070 |
| Neutrons           | E<10      | 0.0003 |
|                    | 10<E      | 0.0012 |

| Flux (10^9 Hertz/microAmp) |               |              |
|----------------------------|---------------|--------------|
| Type                       | E Range (MeV) | Side         |
| abs(electr                 | E<10          | 3.43         |
|                            | 10<E          | 1.00         |
| Photons                    | E<10          | 62.90        |
|                            | 10<E          | 4.55         |
| Neutrons                   | E<10          | High -> 2.99 |
|                            | 10<E          | 0.037        |

| Flux (10^9 Hertz/microAmp) |               |          |
|----------------------------|---------------|----------|
| Type                       | E Range (MeV) | Side     |
| abs(electr                 | E<10          | 3.70E+00 |
|                            | 10<E          | 1.08E+00 |
| Photons                    | E<10          | 8.31E+01 |
|                            | 10<E          | 5.74E+00 |
| Neutrons                   | E<10          | 3.01E+00 |
|                            | 10<E          | 7.49E-02 |

| Flux (10^9 Hertz/microAmp) |           |          |
|----------------------------|-----------|----------|
| Type                       | Range (Me | Top      |
| abs(electr                 | E<10      | 2.05E+01 |
|                            | 10<E      | 9.42E+00 |
| Photons                    | E<10      | 6.41E+02 |
|                            | 10<E      | 1.93E+01 |
| Neutrons                   | E<10      | 1.79E+00 |
|                            | 10<E      | 1.34E-01 |

| Flux (10^9 Hertz/microAmp) |               |          |
|----------------------------|---------------|----------|
| Type                       | E Range (MeV) | Top      |
| abs(electr                 | E<10          | 9.07E-01 |
|                            | 0<E<100       | 1.81E-02 |
|                            | 100<E         | 2.50E-03 |
| Photons                    | E<10          | 6.17E+01 |
|                            | 0<E<100       | 1.86E-01 |
|                            | 100<E         | 5.62E-03 |
| Neutrons                   | E<10          | 2.39E+00 |
|                            | 0<E<100       | 3.00E-02 |
|                            | 100<E         | 2.50E-02 |

| Flux (10^9 Hertz/microAmp) |               |          |
|----------------------------|---------------|----------|
| Type                       | E Range (MeV) | Top      |
| abs(electr                 | E<10          | 1.11E+00 |
|                            | 0<E<100       | 1.87E-02 |
|                            | 100<E         | 0.00E+00 |
| Photons                    | E<10          | 7.90E+01 |
|                            | 0<E<100       | 3.12E-01 |
|                            | 100<E         | 0.00E+00 |
| Neutrons                   | E<10          | 2.24E+00 |
|                            | 0<E<100       | 1.87E-02 |
|                            | 100<E         | 3.12E-02 |

# Precision of simulation

Running the full shielding sim 3 times for statistics

Power (W/microAmp)

| Type      | E Range (MeV) | Side          | $\sigma$ | % error |
|-----------|---------------|---------------|----------|---------|
| Electrons | E<10          | <b>0.0006</b> | 4.0E-05  | 7.1%    |
|           | 10<E          | <b>0.0523</b> | 6.4E-03  | 12.3%   |
| Photons   | E<10          | <b>0.0084</b> | 8.2E-05  | 1.0%    |
|           | 10<E          | <b>0.0649</b> | 9.8E-03  | 15.1%   |
| Neutrons  | E<10          | <b>0.0000</b> | 4.3E-06  | 26.4%   |
|           | 10<E          | <b>0.0018</b> | 4.3E-04  | 24.6%   |

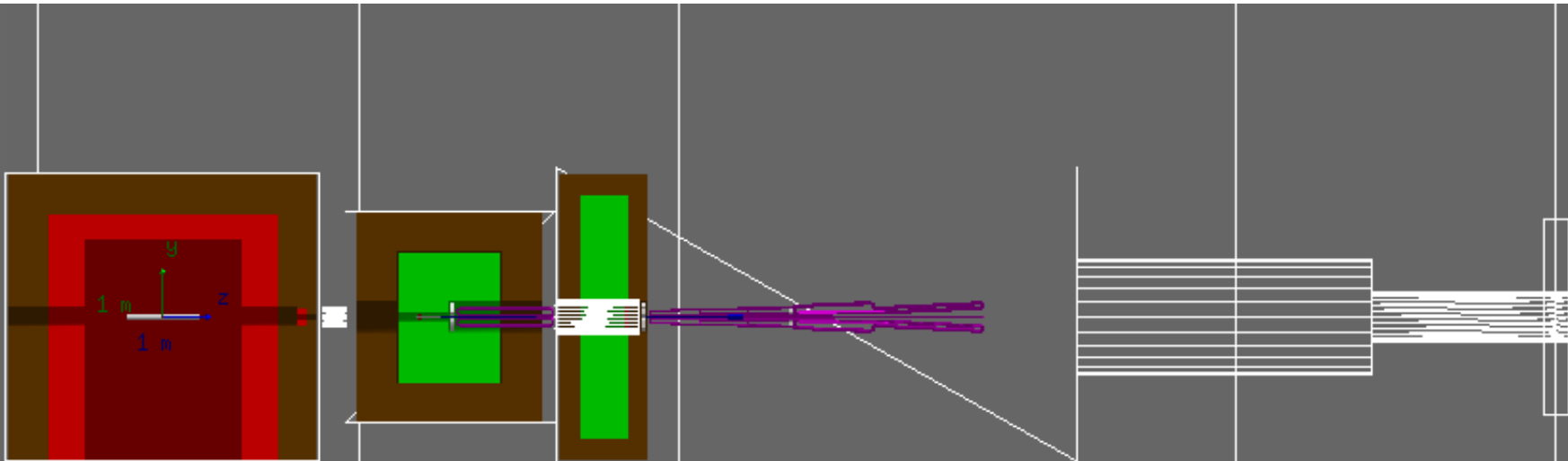
Flux (10<sup>9</sup> Hertz/microAmp)

| Type      | E Range (MeV) | Side           | $\sigma$ | % error |
|-----------|---------------|----------------|----------|---------|
| Electrons | E<10          | <b>3.8E+00</b> | 2.8E-01  | 7.4%    |
|           | 10<E          | <b>1.0E+00</b> | 9.0E-02  | 8.6%    |
| Photons   | E<10          | <b>8.4E+01</b> | 1.3E+00  | 1.6%    |
|           | 10<E          | <b>5.7E+00</b> | 5.6E-02  | 1.0%    |
| Neutrons  | E<10          | <b>2.9E+00</b> | 7.8E-02  | 2.7%    |
|           | 10<E          | <b>8.7E-02</b> | 1.8E-02  | 20.2%   |

Flux (10<sup>9</sup> Hertz/microAmp)

| Type     | E Range (MeV) | Top            | $\sigma$ | % error |
|----------|---------------|----------------|----------|---------|
| Electron | E<10          | <b>1.1E+00</b> | 1.1E-01  | 10.6%   |
|          | 0<E<100       | <b>1.7E-02</b> | 2.9E-03  | 17.7%   |
|          | 100<E         | <b>0.0E+00</b> | 0.0E+00  | xx      |
| Photons  | E<10          | <b>8.0E+01</b> | 1.6E+00  | 2.0%    |
|          | 0<E<100       | <b>2.7E-01</b> | 2.9E-02  | 10.6%   |
|          | 100<E         | <b>0.0E+00</b> | 0.0E+00  | xx      |
| Neutron  | E<10          | <b>2.3E+00</b> | 7.5E-02  | 3.2%    |
|          | 0<E<100       | <b>4.2E-02</b> | 1.6E-02  | 39.4%   |
|          | 100<E         | <b>2.5E-02</b> | 1.3E-02  | 54.0%   |

# First order: remove the hybrid toroid's hut



- This introduces more skyshine and radiation to the hall.
- This leaves a shield around the hybrid and collimator 4 area (and saves money).

# First order: remove the hybrid toroid's hut

- The additional radiation is manageable:
- Lets compare proof of concept shielding and PREX-II to removing the hybrid shield.
- Radiation flux reaching the top of the Hall

PREX-II's Numbers

| Flux (10 <sup>9</sup> Hertz/microAmp) |         |          |
|---------------------------------------|---------|----------|
| Type                                  | E (MeV) | Top      |
| Electrons                             | E<10    | 2.05E+01 |
|                                       | E>10    | 9.42E+00 |
| Photons                               | E<10    | 6.41E+02 |
|                                       | E>10    | 1.93E+01 |
| Neutrons                              | E<10    | 1.79E+00 |
|                                       | E>10    | 1.34E-01 |

Proof of Concept's Numbers

| Flux (10 <sup>9</sup> Hertz/microAmp) |         |          |
|---------------------------------------|---------|----------|
| Type                                  | E (MeV) | Top      |
| Electrons                             | E<10    | 1.08E+00 |
|                                       | E>10    | 1.66E-02 |
| Photons                               | E<10    | 7.97E+01 |
|                                       | E>10    | 2.73E-01 |
| Neutrons                              | E<10    | 2.34E+00 |
|                                       | E>10    | 6.66E-02 |

Remove Hybrid Shield

| Flux (10 <sup>9</sup> Hertz/microAmp) |         |          |
|---------------------------------------|---------|----------|
| Type                                  | E (MeV) | Top      |
| Electrons                             | E<10    | 1.44E+01 |
|                                       | E>10    | 1.51E+01 |
| Photons                               | E<10    | 6.93E+02 |
|                                       | E>10    | 2.87E+01 |
| Neutrons                              | E<10    | 8.83E+00 |
|                                       | E>10    | 1.12E-01 |

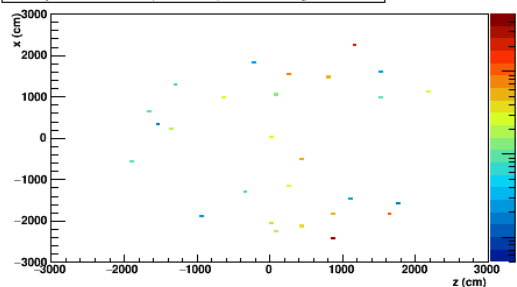
| Factor increase relative to |         |
|-----------------------------|---------|
| PREX II                     | Concept |
| 0.7                         | 13.3    |
| 1.6                         | 908.8   |
| 1.1                         | 8.7     |
| 1.5                         | 105.2   |
| 4.9                         | 3.8     |
| 0.8                         | 1.7     |



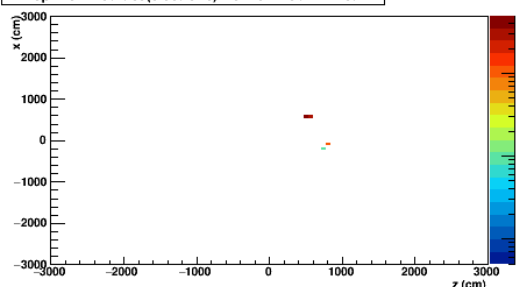
# Rakitha's starting point (all scales arbitrary), top of hall radiation maps vs. vertices

Electrons  
hitting hall  
top vs.  
vertex

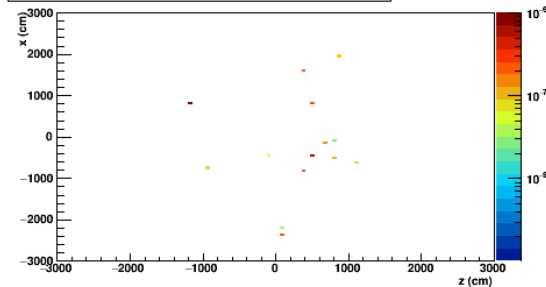
Top Disk. Det: abs(electrons) from ShTarget Area



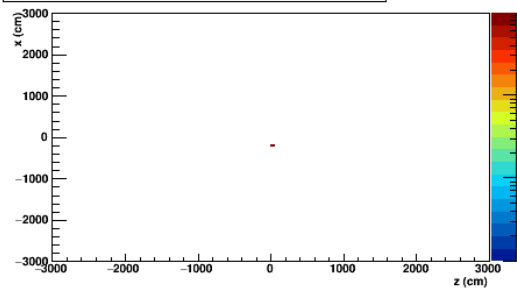
Top Disk. Det: abs(electrons) from ShBlock-1 Area



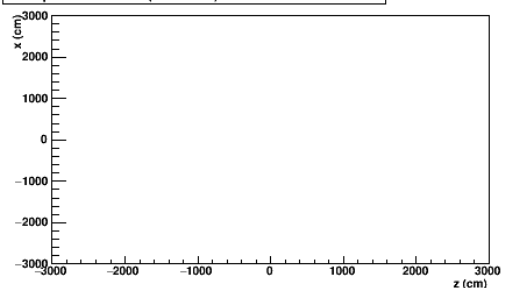
Top Disk. Det: abs(electrons) from ShBlock-2 Area



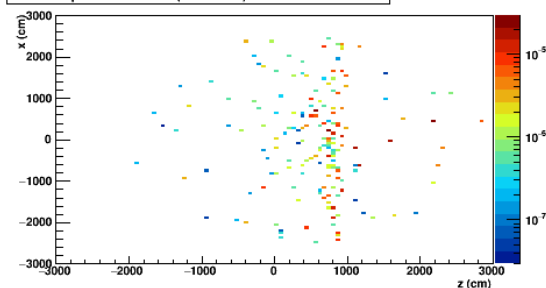
Top Disk. Det: abs(electrons) from ShBlock-3 Area



Top Disk. Det: abs(electrons) from ShBlock-4 Area

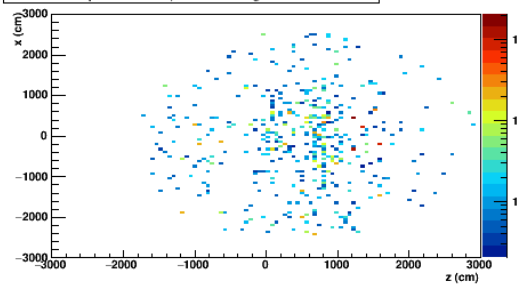


Top Disk. Det: abs(electrons) from All Area

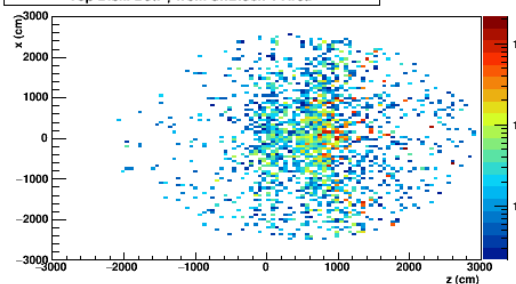


Photons  
hitting hall  
top vs.  
vertex

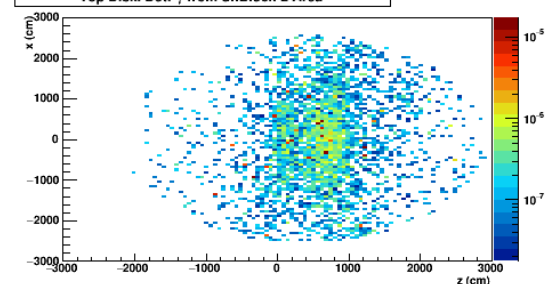
Top Disk. Det:  $\gamma$  from ShTarget Area



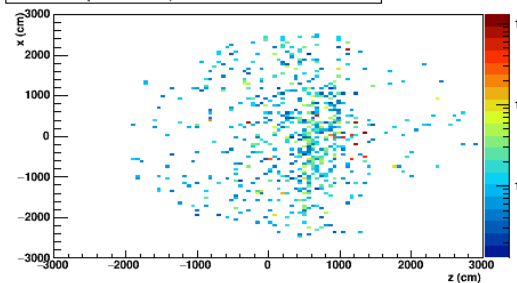
Top Disk. Det:  $\gamma$  from ShBlock-1 Area



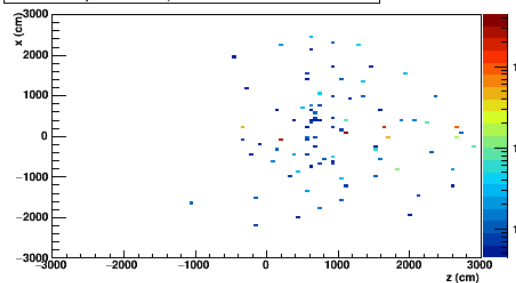
Top Disk. Det:  $\gamma$  from ShBlock-2 Area



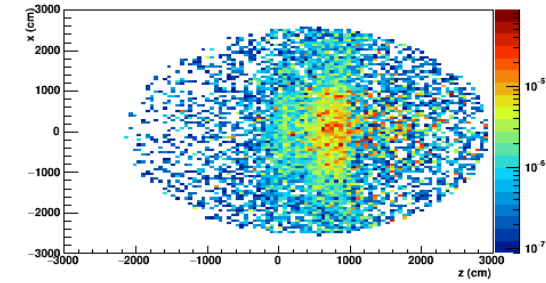
Top Disk. Det:  $\gamma$  from ShBlock-3 Area



Top Disk. Det:  $\gamma$  from ShBlock-4 Area



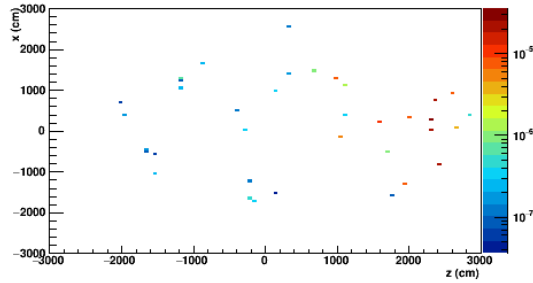
Top Disk. Det:  $\gamma$  from All Area



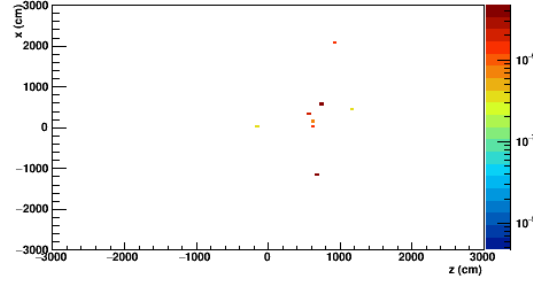
# Removing the hybrid shielding block (all scales arbitrary)

Electrons  
hitting hall  
top vs.  
vertex

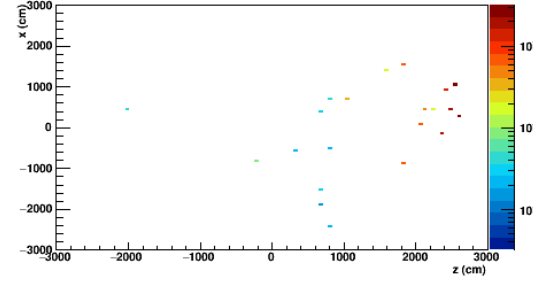
Top Disk. Det: abs(electrons) from ShTarget Area



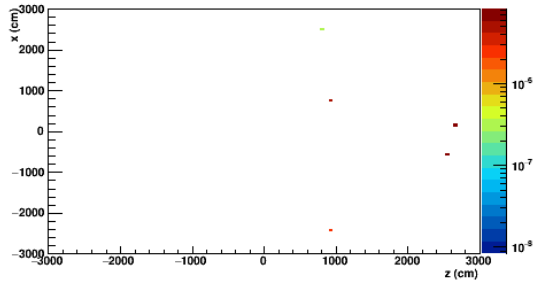
Top Disk. Det: abs(electrons) from ShBlock-1 Area



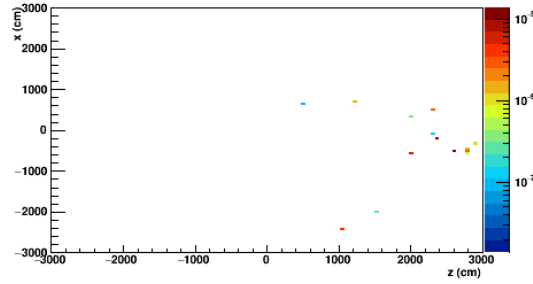
Top Disk. Det: abs(electrons) from ShBlock-2 Area



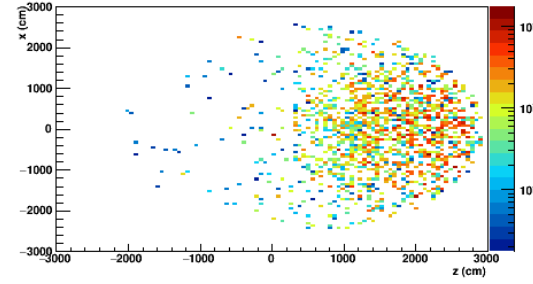
Top Disk. Det: abs(electrons) from ShBlock-3 Area



Top Disk. Det: abs(electrons) from ShBlock-4 Area

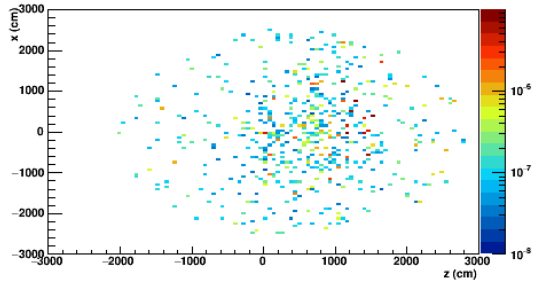


Top Disk. Det: abs(electrons) from All Area

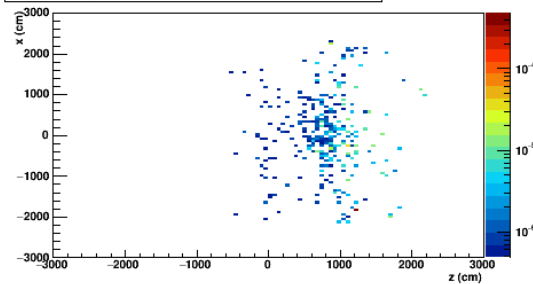


Photons  
hitting hall  
top vs.  
vertex

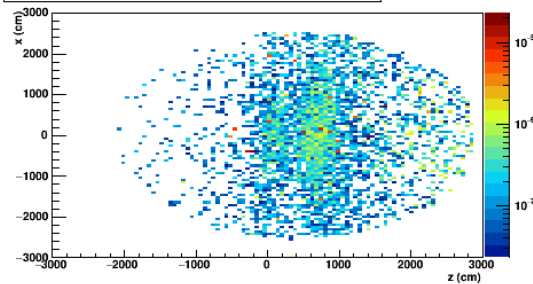
Top Disk. Det:  $\gamma$  from ShTarget Area



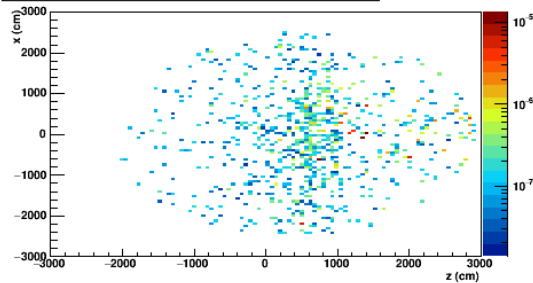
Top Disk. Det:  $\gamma$  from ShBlock-1 Area



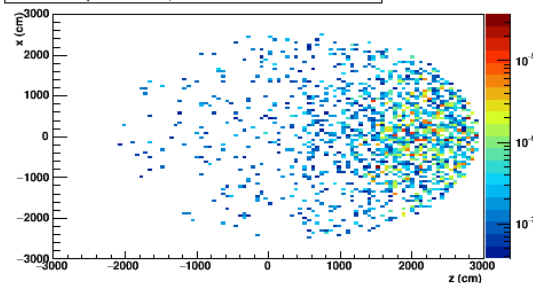
Top Disk. Det:  $\gamma$  from ShBlock-2 Area



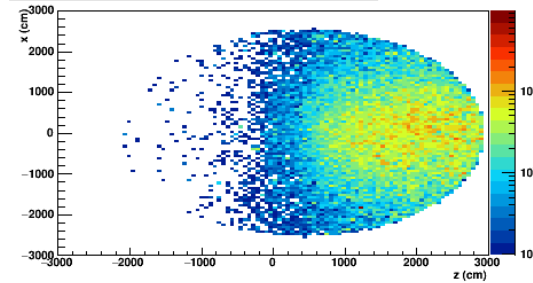
Top Disk. Det:  $\gamma$  from ShBlock-3 Area



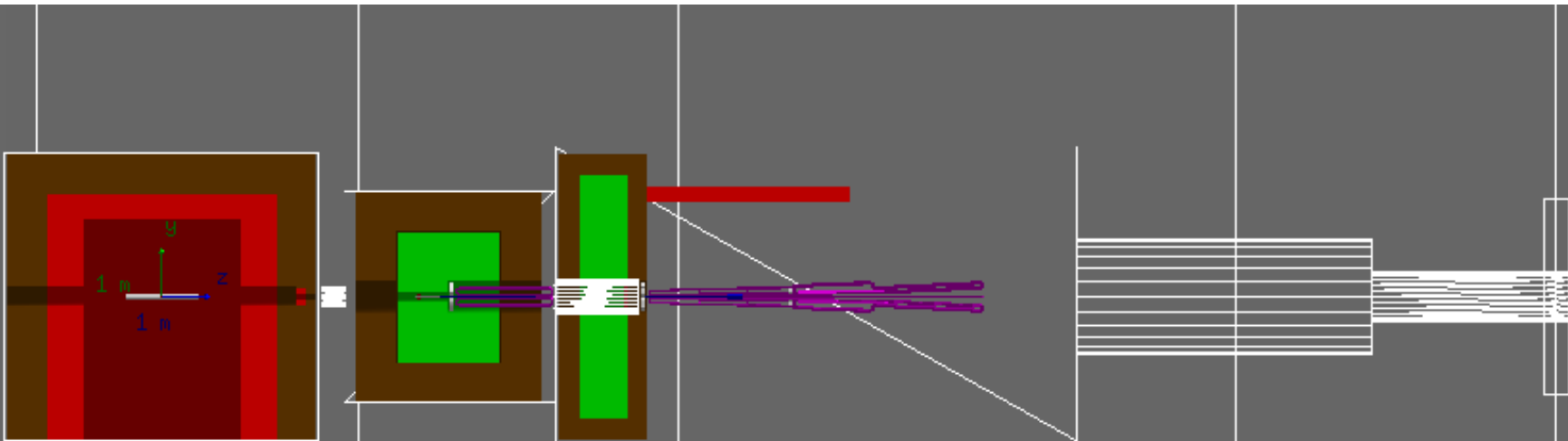
Top Disk. Det:  $\gamma$  from ShBlock-4 Area



Top Disk. Det:  $\gamma$  from All Area



# Implementing some shielding: 30 cm Lead roof segments



I did one roof that completely covered the hybrid magnet, as well as the one shown above which is  $\frac{1}{4}$  that size with negligible increase in radiation over the full roof.

# Preliminary data

Checking Rakitha's  
Proof of Concept

| Flux (10 <sup>9</sup> Hertz/microAmp) |            |                 |
|---------------------------------------|------------|-----------------|
| Type                                  | Range      | Top             |
| e <sup>-</sup>                        | E<10 (MeV) | <b>1.08E+00</b> |
|                                       | 10<E<100   | <b>1.66E-02</b> |
|                                       | 100<E      | <b>0.00E+00</b> |
| γ                                     | E<10       | <b>7.97E+01</b> |
|                                       | 10<E<100   | <b>2.73E-01</b> |
|                                       | 100<E      | <b>0.00E+00</b> |
| n <sup>0</sup>                        | E<10       | <b>2.34E+00</b> |
|                                       | 10<E<100   | <b>4.16E-02</b> |
|                                       | 100<E      | <b>2.50E-02</b> |

Completely removing the  
hybrid shielding block

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 | Δ Factor     |
|---------------------------------------|----------|-----------------|--------------|
| Type                                  | Range    | Top             | Proof        |
| e <sup>-</sup>                        | E<10     | <b>1.44E+01</b> | <b>13.3</b>  |
|                                       | 10<E<100 | <b>7.93E+00</b> | <b>476.3</b> |
|                                       | 100<E    | <b>7.20E+00</b> | x            |
| γ                                     | E<10     | <b>6.93E+02</b> | <b>8.7</b>   |
|                                       | 10<E<100 | <b>2.65E+01</b> | <b>97.3</b>  |
|                                       | 100<E    | <b>2.15E+00</b> | x            |
| n <sup>0</sup>                        | E<10     | <b>8.83E+00</b> | 3.8          |
|                                       | 10<E<100 | <b>3.75E-02</b> | 0.9          |
|                                       | 100<E    | <b>7.49E-02</b> | 3.0          |

Adding in a roof

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 | Δ Factor   |
|---------------------------------------|----------|-----------------|------------|
| Type                                  | Range    | Top             | Proof      |
| e <sup>-</sup>                        | E<10     | <b>2.68E+00</b> | 2.5        |
|                                       | 10<E<100 | <b>1.31E-01</b> | <b>7.9</b> |
|                                       | 100<E    | <b>0.00E+00</b> | 0.0        |
| γ                                     | E<10     | <b>2.01E+02</b> | 2.5        |
|                                       | 10<E<100 | <b>2.75E-01</b> | 1.0        |
|                                       | 100<E    | <b>0.00E+00</b> | 0.0        |
| n <sup>0</sup>                        | E<10     | <b>6.07E+00</b> | 2.6        |
|                                       | 10<E<100 | <b>5.62E-02</b> | 1.4        |
|                                       | 100<E    | <b>1.87E-02</b> | 0.7        |

Removing 3/4 of the roof

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 | Δ Factor    |
|---------------------------------------|----------|-----------------|-------------|
| Type                                  | Range    | Top             | Proof       |
| e <sup>-</sup>                        | E<10     | <b>4.38E+00</b> | 4.1         |
|                                       | 10<E<100 | <b>8.05E-01</b> | <b>48.4</b> |
|                                       | 100<E    | <b>0.00E+00</b> | 0.0         |
| γ                                     | E<10     | <b>2.84E+02</b> | 3.6         |
|                                       | 10<E<100 | <b>6.12E-01</b> | 2.2         |
|                                       | 100<E    | <b>0.00E+00</b> | 0.0         |
| n <sup>0</sup>                        | E<10     | <b>6.67E+00</b> | 2.8         |
|                                       | 10<E<100 | <b>3.12E-02</b> | 0.7         |
|                                       | 100<E    | <b>4.37E-02</b> | 1.8         |

PREX II Values

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 |
|---------------------------------------|----------|-----------------|
| Type                                  | Range    | Top             |
| e <sup>-</sup>                        | E<10     | <b>2.05E+01</b> |
|                                       | 10<E<100 | <b>9.42E+00</b> |
| γ                                     | E<10     | <b>6.41E+02</b> |
|                                       | 10<E<100 | <b>1.93E+01</b> |
| n <sup>0</sup>                        | E<10     | <b>1.79E+00</b> |
|                                       | 10<E<100 | <b>1.34E-01</b> |

Completely removing the  
hybrid shielding block

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 | Δ Factor   |
|---------------------------------------|----------|-----------------|------------|
| Type                                  | Range    | Top             | PREX II    |
| e <sup>-</sup>                        | E<10     | <b>1.44E+01</b> | 0.7        |
|                                       | 10<E<100 | <b>1.51E+01</b> | 1.6        |
| γ                                     | E<10     | <b>6.93E+02</b> | 1.1        |
|                                       | 10<E<100 | <b>2.87E+01</b> | 1.5        |
| n <sup>0</sup>                        | E<10     | <b>8.83E+00</b> | <b>4.9</b> |
|                                       | 10<E<100 | <b>1.12E-01</b> | 0.8        |

Adding in a roof

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 | Δ Factor |
|---------------------------------------|----------|-----------------|----------|
| Type                                  | Range    | Top             | PREX II  |
| e <sup>-</sup>                        | E<10     | <b>2.68E+00</b> | 0.1      |
|                                       | 10<E<100 | <b>1.31E-01</b> | 0.0      |
| γ                                     | E<10     | <b>2.01E+02</b> | 0.3      |
|                                       | 10<E<100 | <b>2.75E-01</b> | 0.0      |
| n <sup>0</sup>                        | E<10     | <b>6.07E+00</b> | 3.4      |
|                                       | 10<E<100 | <b>7.49E-02</b> | 0.6      |

Removing 3/4 of the roof

| Flux (10 <sup>9</sup> Hertz/microAmp) |          |                 | Δ Factor   |
|---------------------------------------|----------|-----------------|------------|
| Type                                  | Range    | Top             | PREX II    |
| e <sup>-</sup>                        | E<10     | <b>4.38E+00</b> | 0.2        |
|                                       | 10<E<100 | <b>8.05E-01</b> | 0.1        |
| γ                                     | E<10     | <b>2.84E+02</b> | 0.4        |
|                                       | 10<E<100 | <b>6.12E-01</b> | 0.0        |
| n <sup>0</sup>                        | E<10     | <b>6.67E+00</b> | <b>3.7</b> |
|                                       | 10<E<100 | <b>7.49E-02</b> | 0.6        |

This means that the proof of concept shielding block is blocking many additional electrons and slow neutrons. It appears that a small localized shield is the right way to go, with some tweaks.

# Current Plans

- Fix the previous heat maps to all share color scales so relative changes are obvious.
- Map the Newport News and hall radiation data as a function of the starting point vertex.
- Use that information to design better localized shielding.
- Begin using the JLab ifarm cluster to improve the simulation's precision.
- Determine radiation limits for the JLab area.