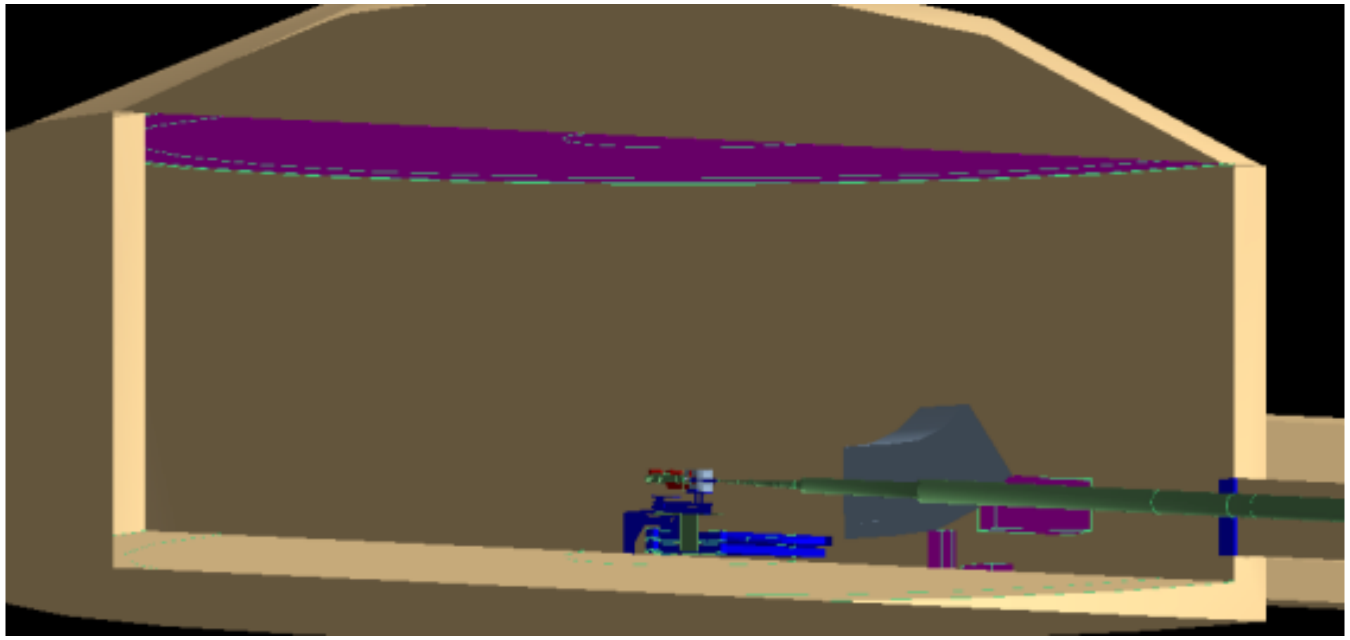
# PREX Dump configuration

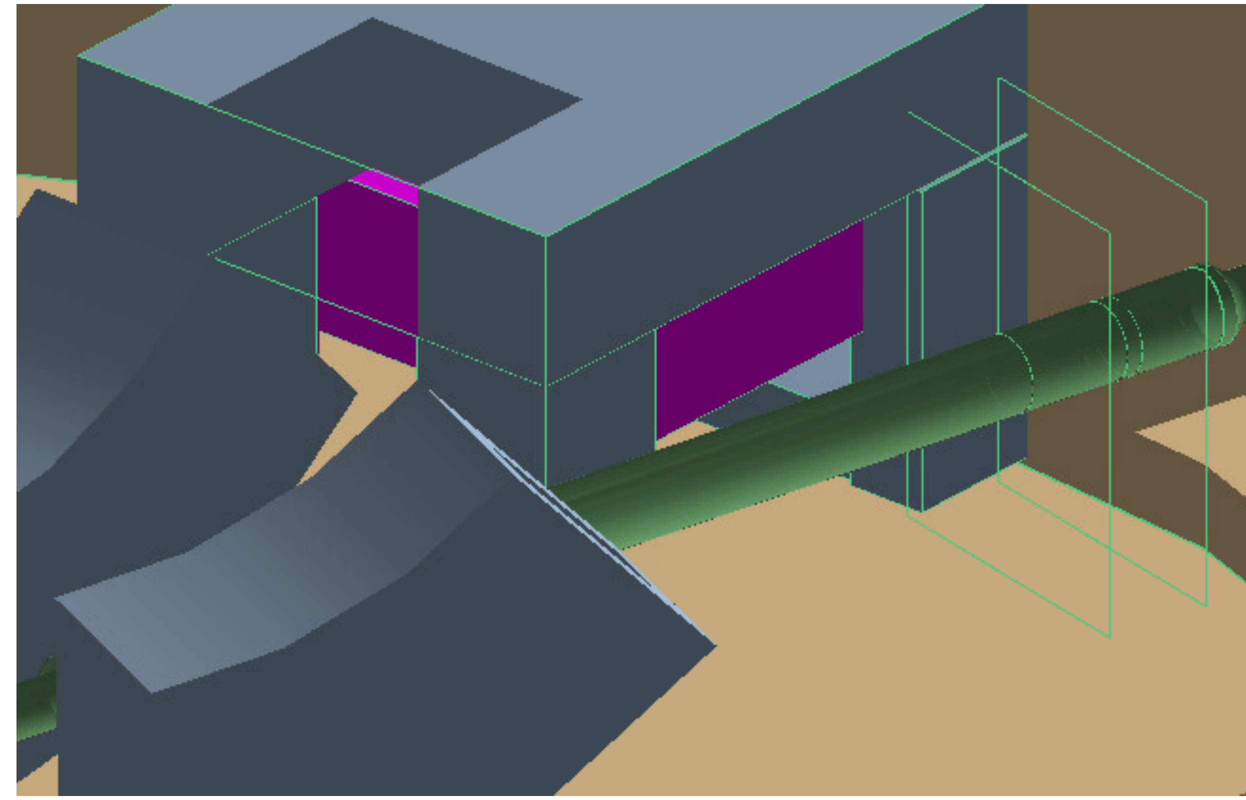
Ciprian Gal
UVa

# Simulation updates

**ERR**



**Update**

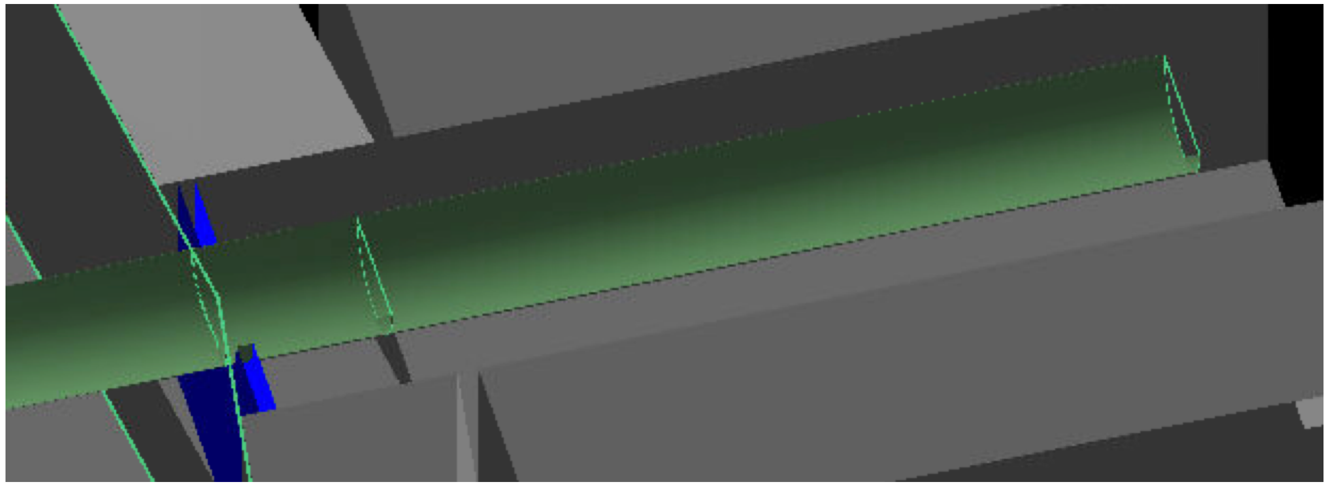


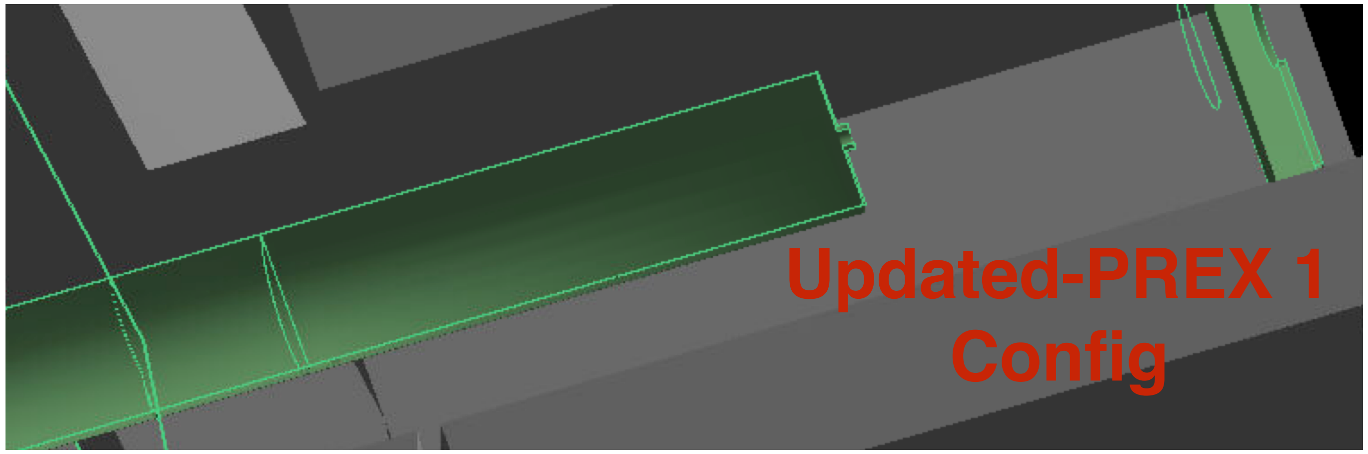
- Since ERR simulation geometry updated:
  - increased the size of the hall to ~26 m (from 25 m) — no visible effect on radiation calculations results
  - use APEX HRS platform geometry to add detail; in particular the legs around the HRS platform electronics
  - measured area where electronics could be placed and placed sensitive detectors to cover the entire area

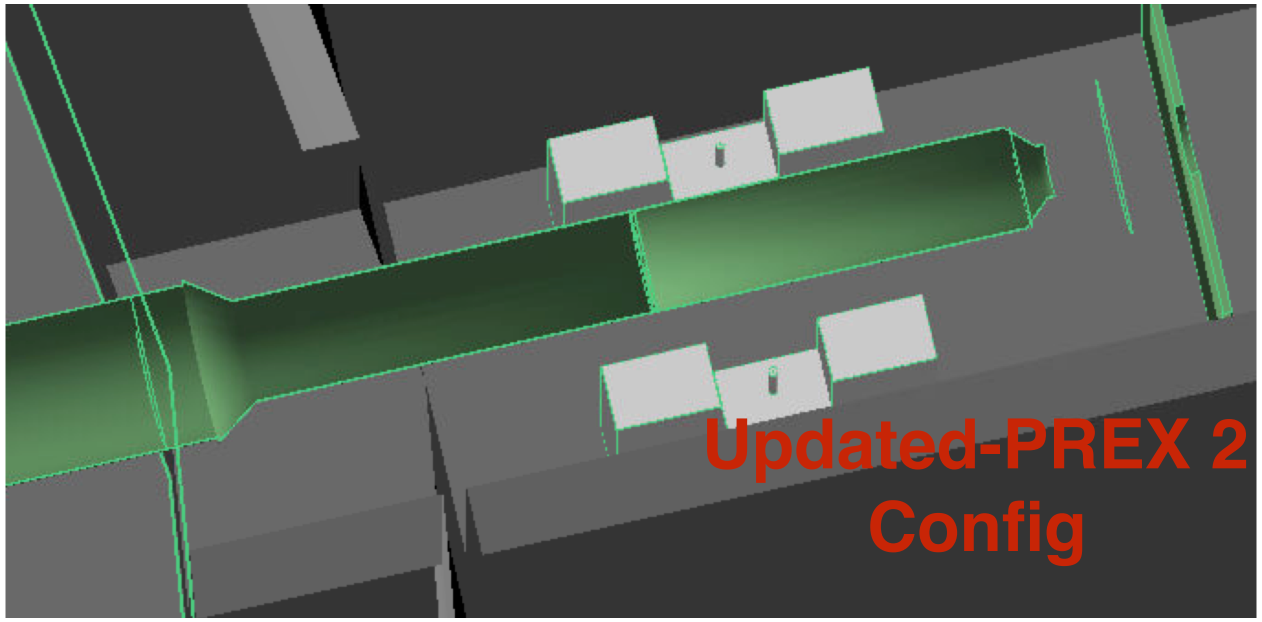
# Simulation updates

## ERR

## Update

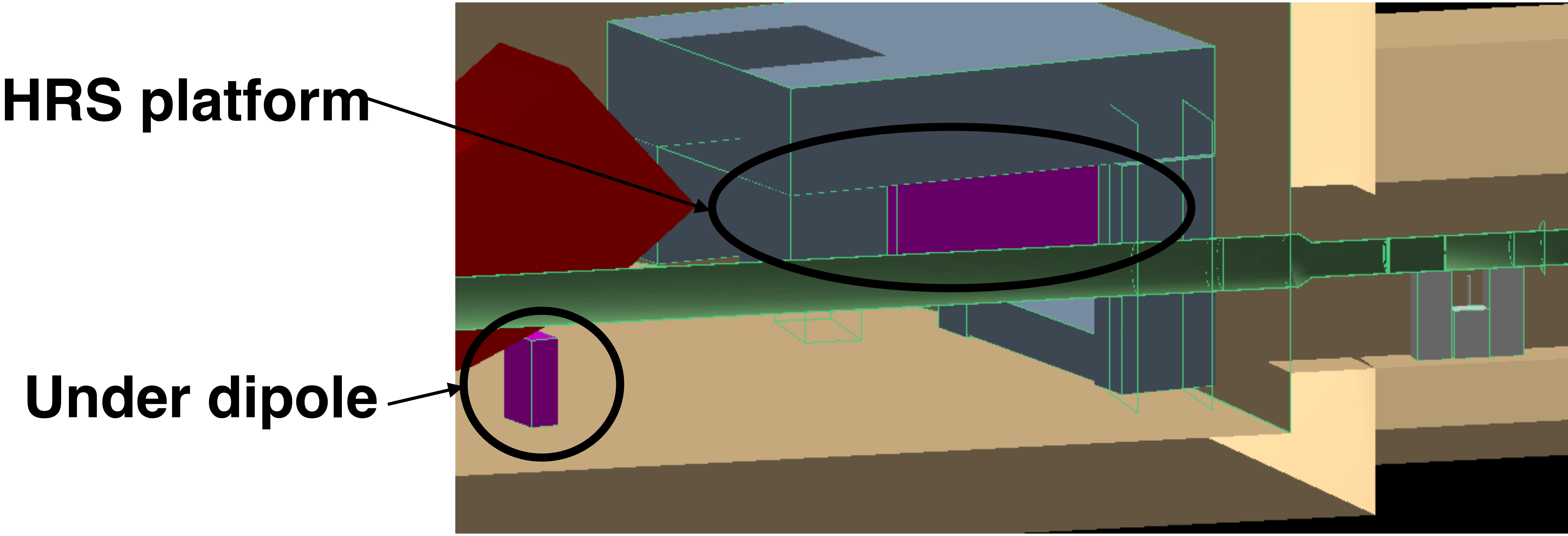





- Dump configuration for ERR:
  - for the ERR we had a thick stainless steel covering the dump entrance to fake splash back from the dump
  - The beam pipe was also open to the back
- Dump configuration update:
  - updated with configurations consistent with JLab Drawings (obtained from Keith Welch) for both PREX1 and PREX2 including the limiting apertures
  - removed stainless steel wall from front and added aluminum wall separating the He region

# Hall radiation (with update)




- Two regions are of interest where we can have softer electronics
- The HRS platform detector covers all possible areas where sensitive electronics could be placed
- The detector under the dipole iron has flow meters that could be affected by radiation

# HRS radiation (with update)

| HRS | PREX2 ERR | PREX2 Update | CREX5 ERR | CREX5 Update |
|---|---|---|---|---|
| HRS rad [NEIL/cm2] (% of PREX1) | 4.1E+09 (9) | 3.1E+10 (99) | 7.4E+09 (16) | 2.7E+10 (89) |

The updated dump configuration brings the integrated radiation to the HRS platform to be level of PREX1 for the combined PREX2 and CREX run.

- The variable of interest is NEIL (which gives a higher importance to neutrons, as compared to EM radiation)
- Performed two PREX1 estimates: a) one with the old configuration to compare to the ERR results b) with the new configuration to compare to the current configurations
- Comparisons with the open detector put PREX2 and CREX each at the level of PREX1 radiation

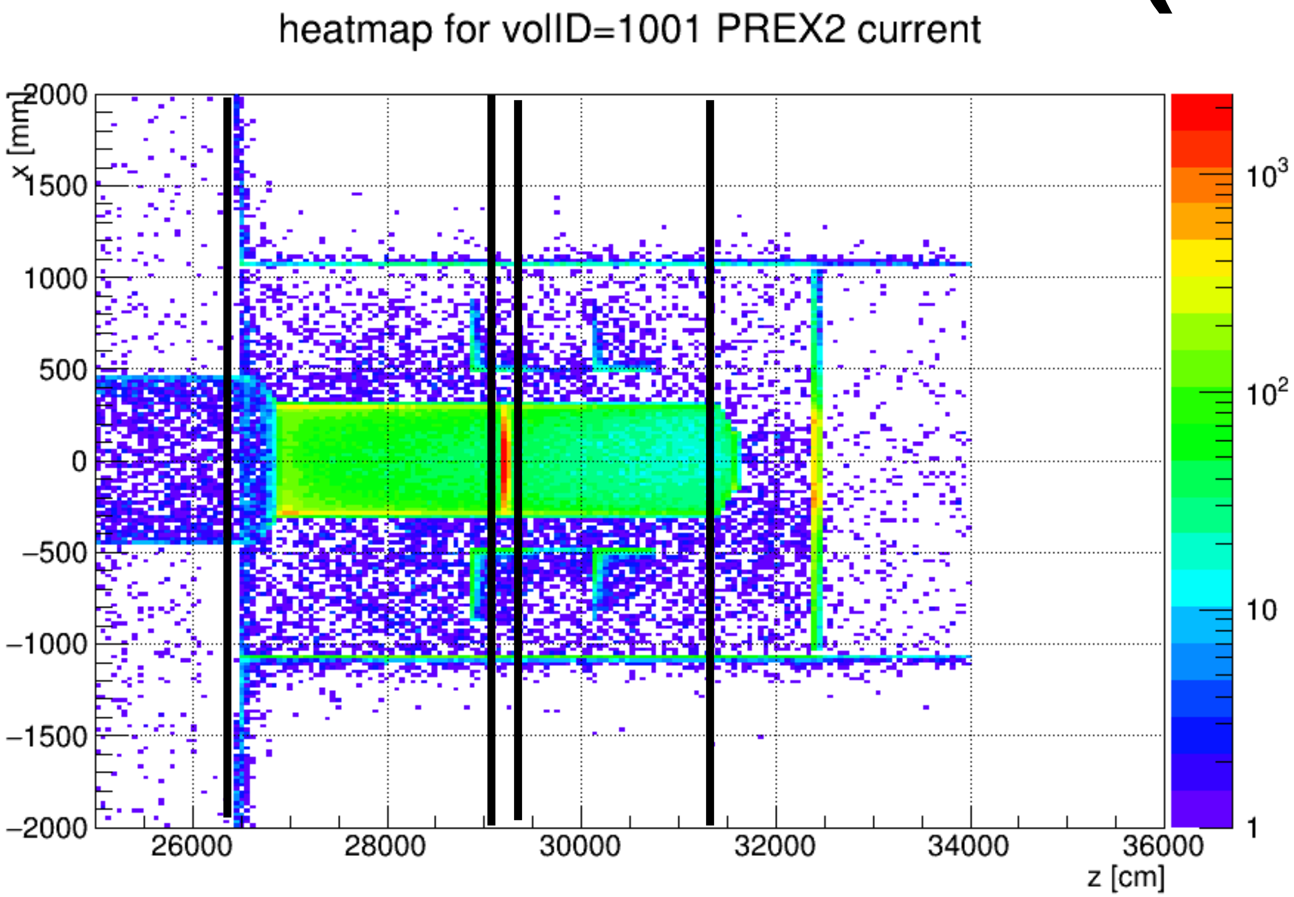
# HRS radiation (with update)

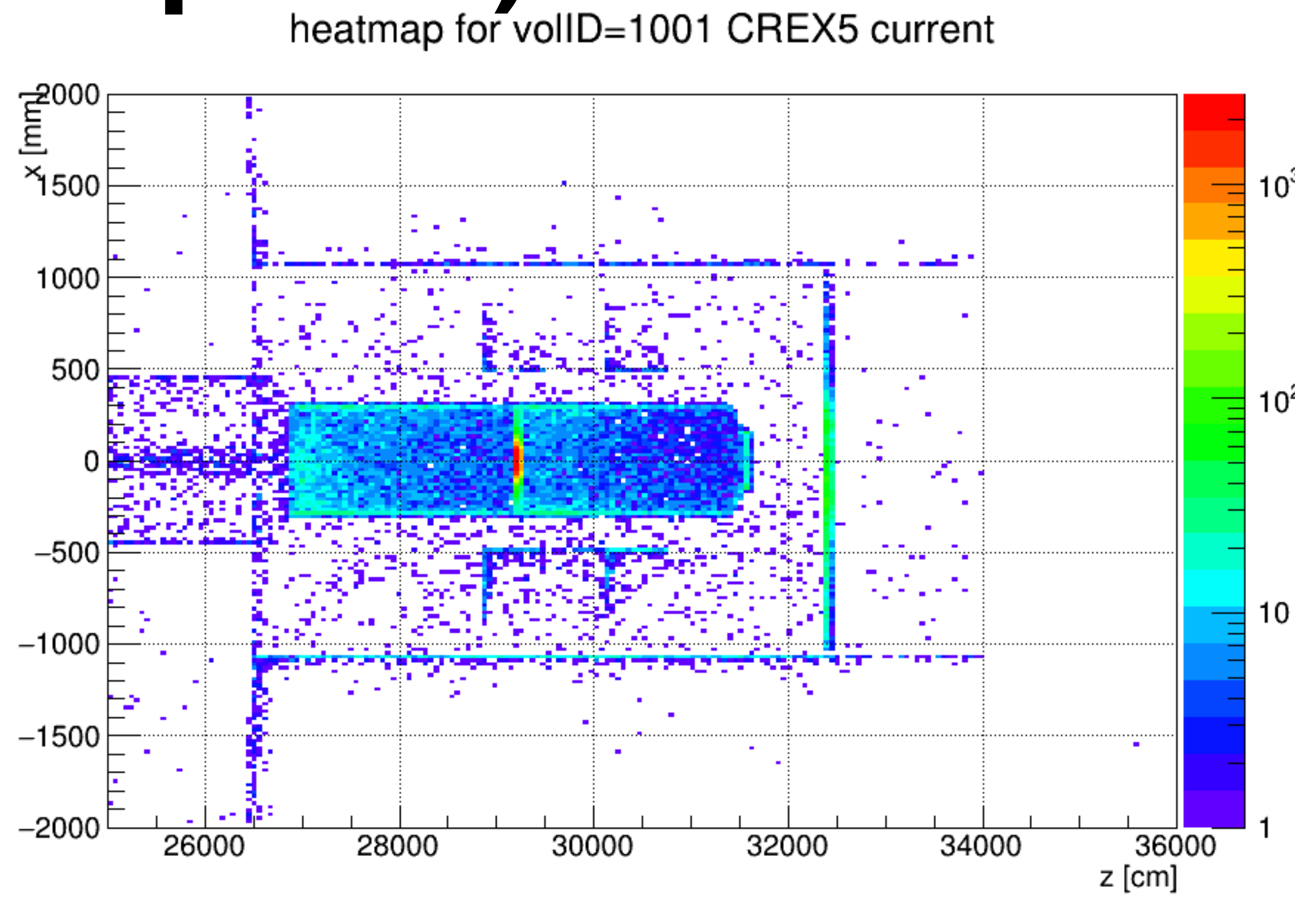
| HRS | PREX2 Update | CREX5 Update |
|---|---|---|
| HRS rad [NEIL/cm2] (% of PREX1) | 3.1E+10 (99) | 2.7E+10 (89) |
| Precent coming from hall | 30 | 29 |

| HRS | PREX2 Update | CREX5 Update |
|---|---|---|
| HRS rad [NEIL/cm2] (% of PREX1) | 3.1E+10 (99) | 2.7E+10 (89) |
| HRS rad (EM) %of Total | 22 | 13 |
| HRS rad (N) %of Total | 78 | 87 |

- With the update we can see that about two thirds of the radiation reaching the HRS platform comes from the dump
  - the ERR evaluation was basically only taking the hall into account (for PREX2 and CREX)
- If we look at the particles that produce the radiation at the HRS platform about 80% is caused by neutrons

# HRS radiation (with update) - counts

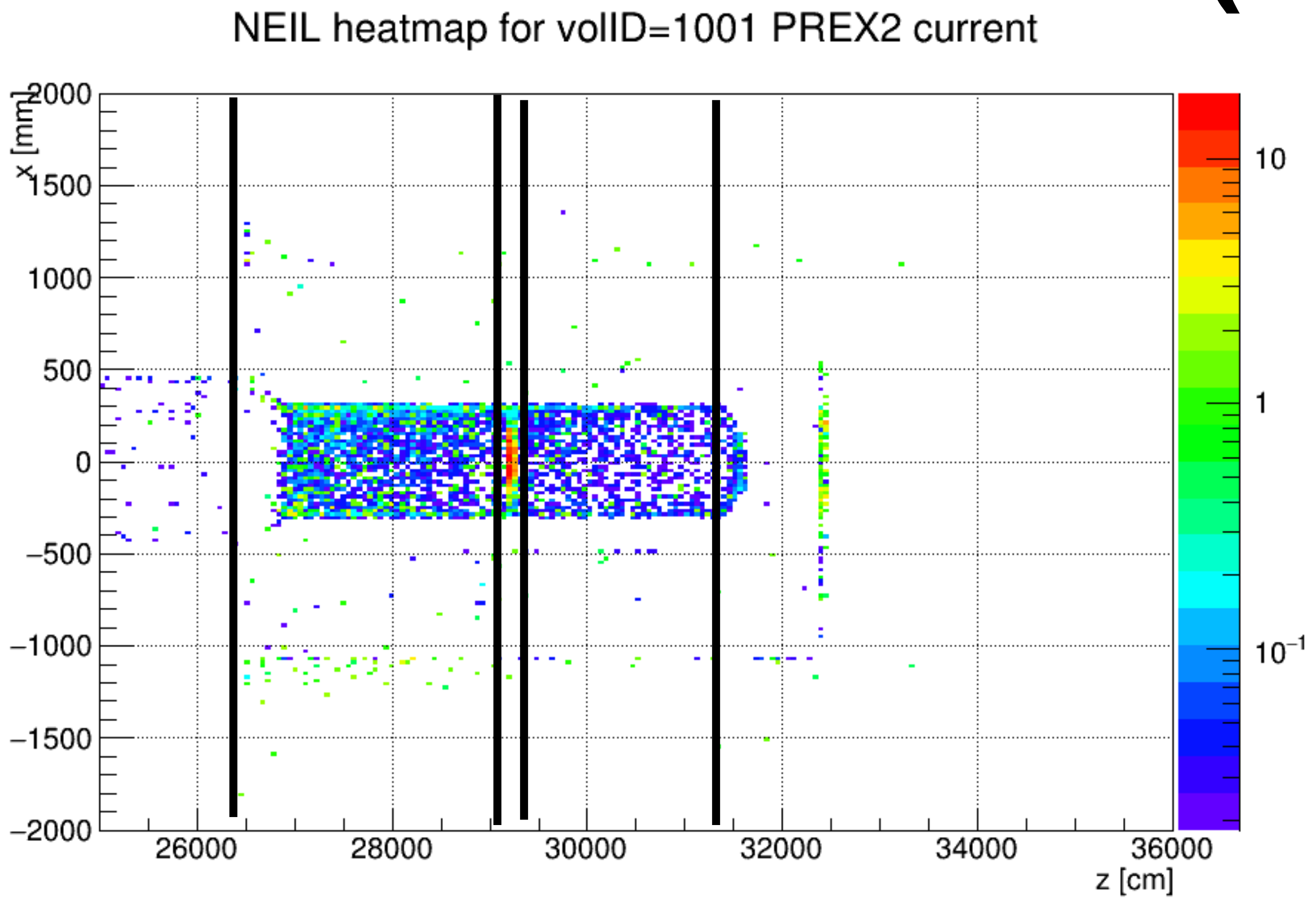


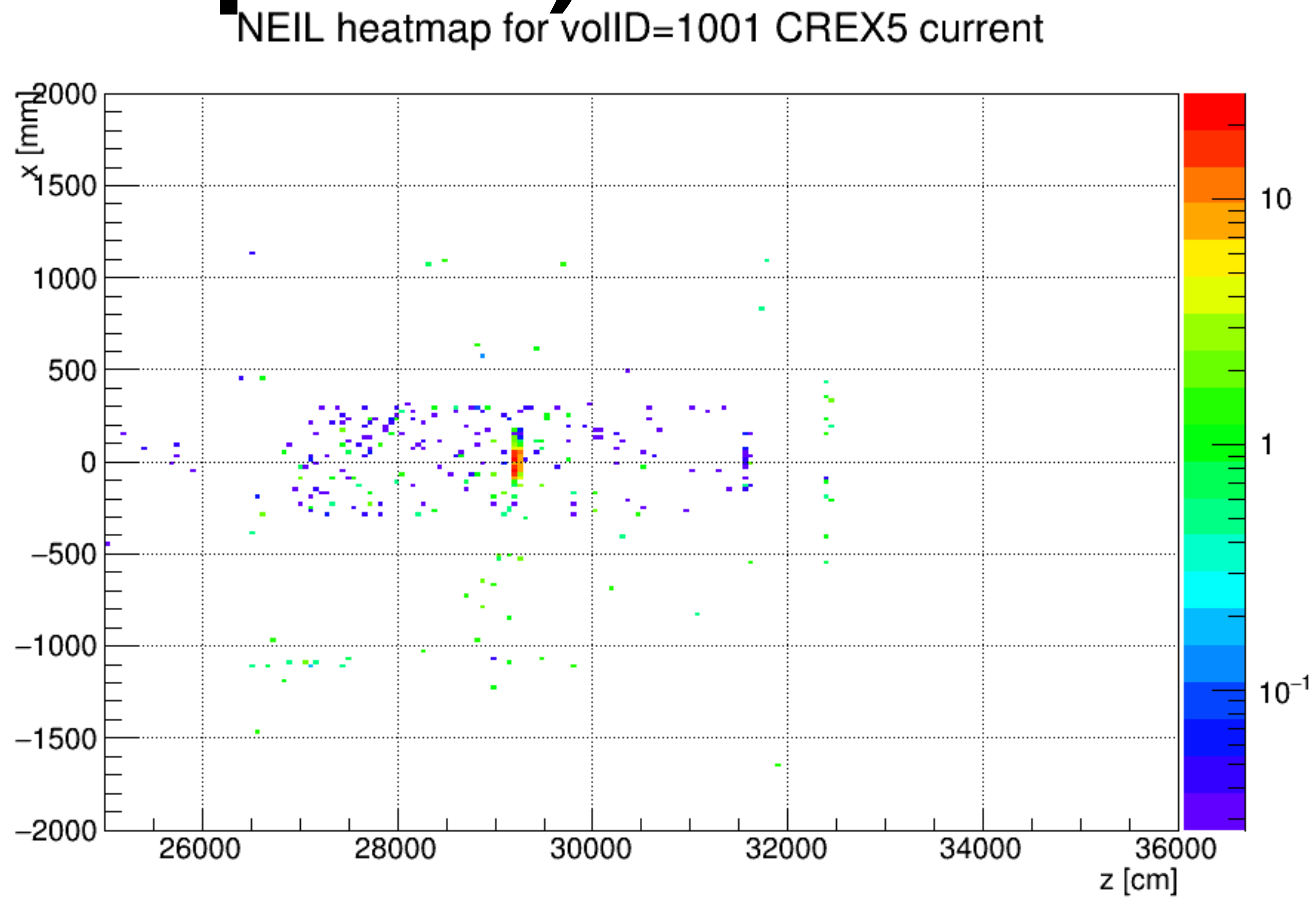




| | R1(25 to 26.4) | R2 (26.4 to 29.15) | R3 (29.15 to 29.3) | R4 (29.3 to 31.4) | R5 (31.4 to 36) | Sum |
|---|---|---|---|---|---|---|
| PREX2 | 2830 | 126458 | 54522 | 53472 | 35734 | 273016 |
| CREX | 776 | 12104 | 25649 | 8528 | 5615 | 52672 |
| PREX2 | 1% | 49% | 21% | 21% | 14% | Ratio |
| CREX | 1% | 23% | 49% | 16% | 11% | 19% |

- Total counts for 5e7 electrons on target
- The source counts of (mainly) EM radiation can give us a pretty good estimation of which areas are problematic

# HRS radiation (with update) - NEIL



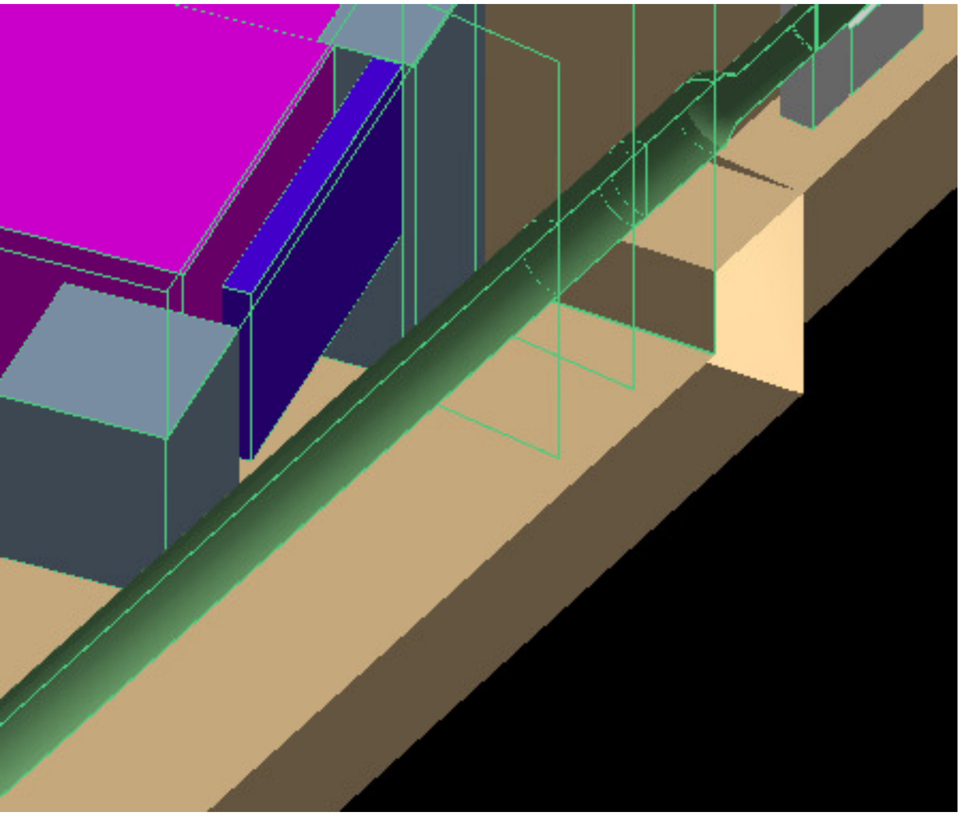

| | R1(25 to 26.4) | R2 (26.4 to 29.15) | R3 (29.15 to 29.3) | R4 (29.3 to 31.4) | R5 (31.4 to 36) | Sum |
|---|---|---|---|---|---|---|
| PREX2 | 13.8906 | 481.32 | 272.651 | 149.928 | 123.957 | 1041.7466 |
| CREX | 2.83061 | 78.5768 | 212.123 | 27.5833 | 18.4478 | 339.56151 |
| PREX2 | 1% | 46% | 26% | 14% | 12% | Ratio |
| CREX | 1% | 23% | 62% | 8% | 5% | 33% |

- The conversion to NEIL clarifies the issues we are facing
- While most of the problem for CREX is the donut, for PREX the neck down, the pipe and donut all contribute

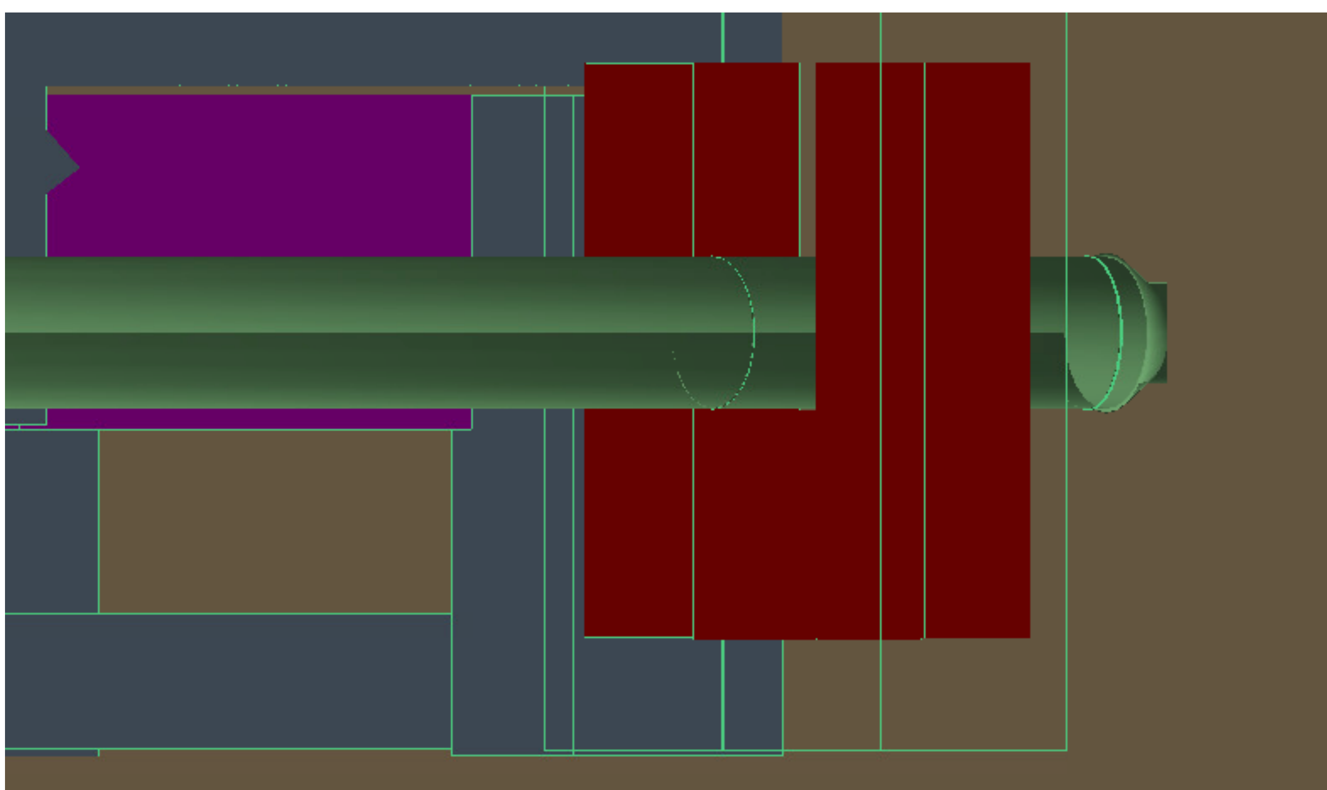
# Considered mitigation strategies

- Increasing the size of the donut hole (fixes most of the problems for CREX)
- Replacing the pipe altogether to a PREX1 style pipe and with an end that matches the current connection to the Al wall will fix all issues for both PREX2 and CREX
- Hiding the neck down and/or donut in the shadow of the collimator:
  - to hide the neck down the collimator will have to be able to absorb more than double the power (the donut is more than a factor of 10)
  - the radiation at the HRS platform will increase if we don't provide additional shielding around the collimator (the area is already pretty much full)
- Shielding the dump/HRS region:
  - we can shield the dump with a wall between the two HRSs
  - we can shield the HRS platform alone with a wall facing the beampipe

# Shielding

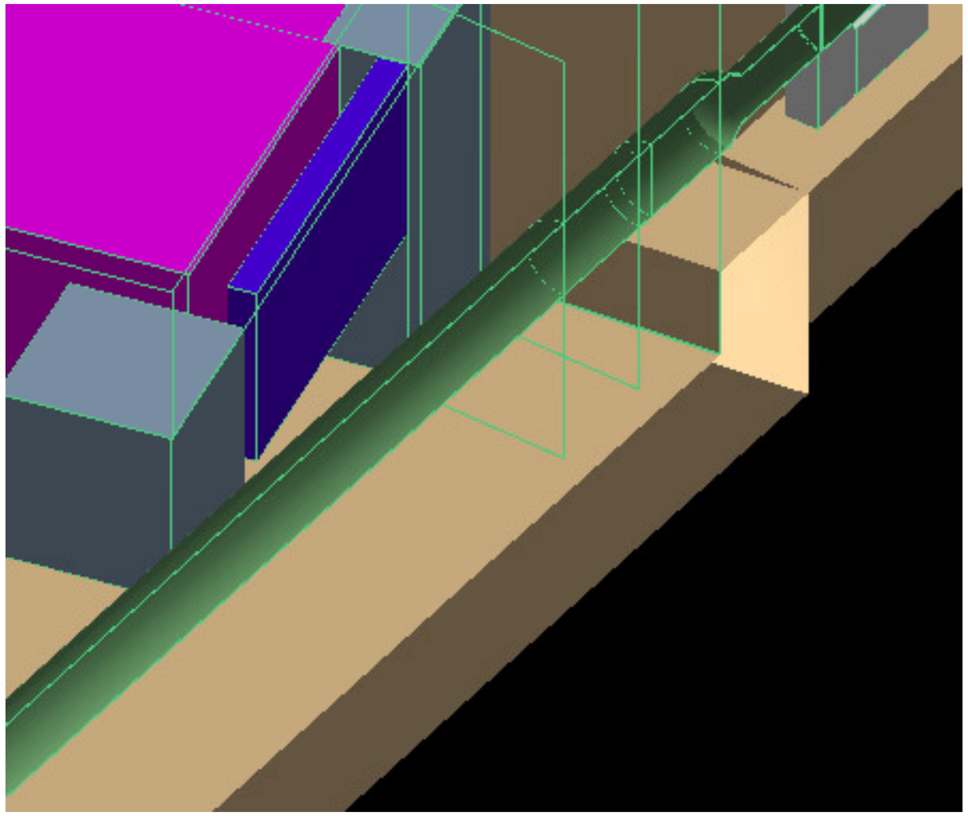


31x210x386 cm3 (5800kg)

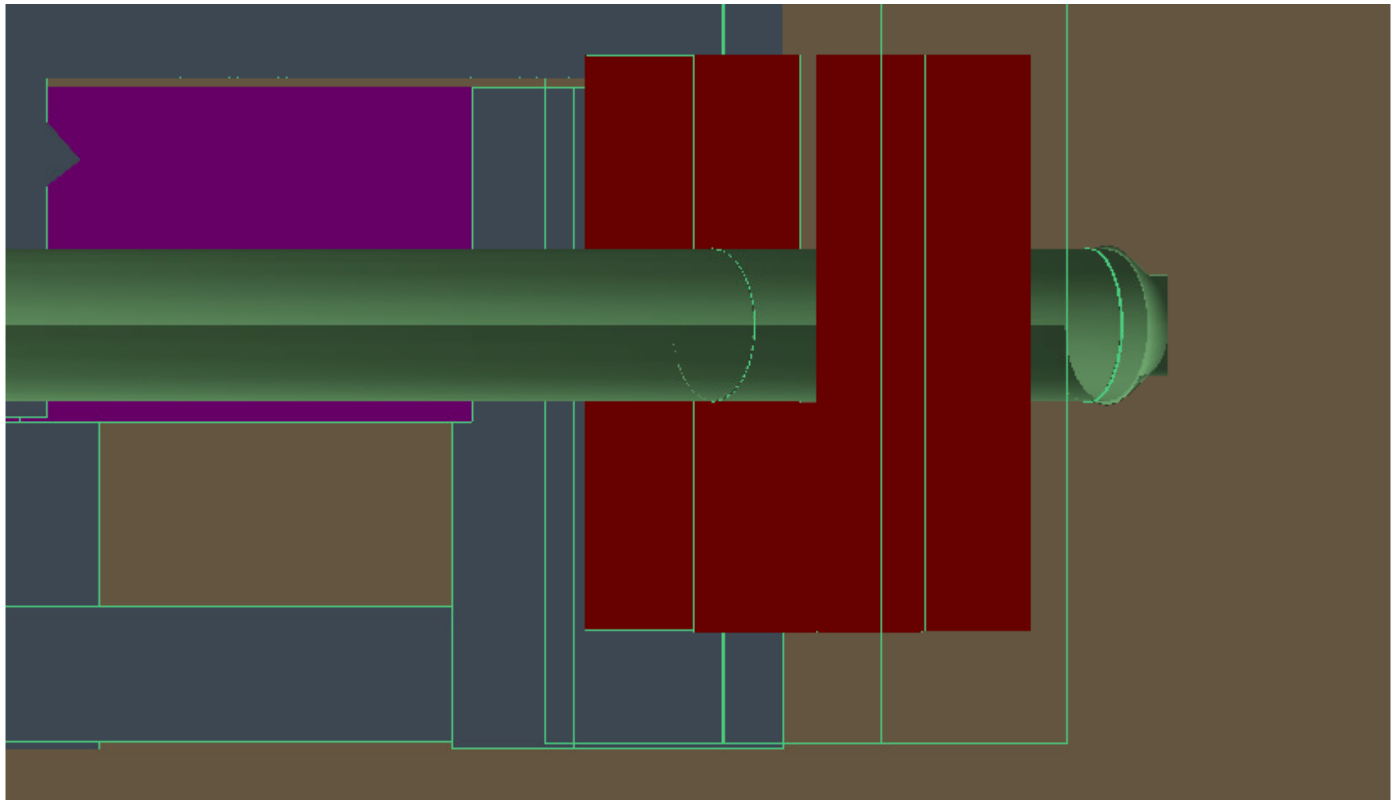


Center: 134x137x45 cm3 (1900 kg)
Sides: 120x344x45 cm3 (4300 kg)

# Shielding



**31x210x386 cm3 (5800kg)**



**Center: 134x137x45 cm3 (1900 kg)**
**Sides: 120x344x45 cm3 (4300 kg)**

- Shielding the HRS platform with a 31 cm thick Concrete wall is very effective (for the HRS platform) but leaves the rest of the hall open (for example the flow meters under the dipole iron)
    - it would also be needed to do it on both platforms (two construction regions instead of 1)
- Shielding the dump with about 45 cm thick Concrete is almost as effective for the HRS platform and it provides additional shielding for the rest of the hall

# Cumulative Radiation levels

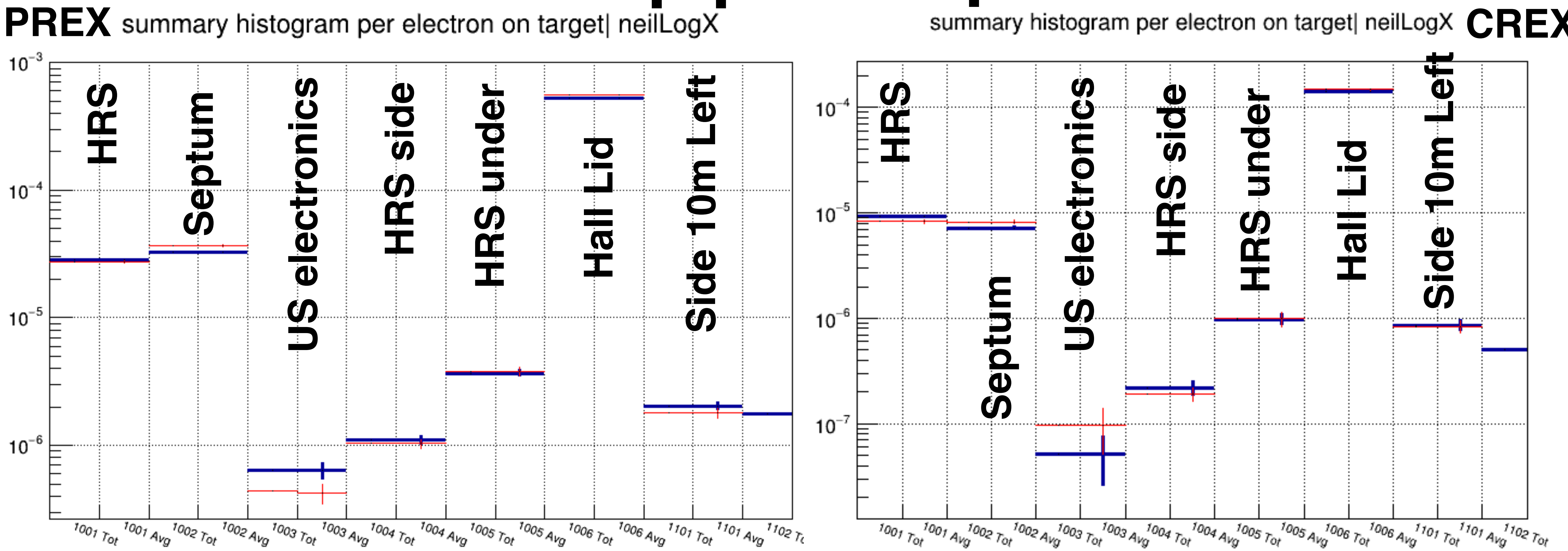
| | | HRS detector | | | | Under detector | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total NEIL/cm2 | uncert | Ratio to P1 | uncert | Total NEIL/cm2 | uncert | Ratio to P1 | uncert |
| | PREX1 (ERR dump) | 4.60E+10 | 1.79E+09 | 1.00 | 0.06 | 7.43E+10 | 4.92E+09 | 1.00 | 0.09 |
| | PREX1 (ERR dump); newHRSDet LargerHall | 3.07E+10 | 4.01E+08 | 0.67 | 0.03 | 9.65E+10 | 2.68E+09 | 1.30 | 0.09 |
| PREX 2 | NewHRSDet | 3.05E+10 | 7.62E+08 | 0.99 | 0.03 | 7.09E+10 | 4.98E+09 | 0.73 | 0.06 |
| | newHRSDet+fatPipe+prex2End | 7.29E+09 | 2.88E+08 | 0.24 | 0.01 | 2.18E+10 | 2.43E+09 | 0.23 | 0.03 |
| | newHRS+sideShield(31cmConc) + 4inDonut | 9.72E+09 | 4.36E+08 | 0.32 | 0.01 | 5.90E+10 | 4.49E+09 | 0.61 | 0.05 |
| | newHRS+DSlargeU(30cmConc)+4inDonut | 1.35E+10 | 4.67E+08 | 0.44 | 0.02 | 1.75E+10 | 2.04E+09 | 0.18 | 0.02 |
| | newHRS+DSlargeU(45cmConc)+4inDonut | 1.18E+10 | 4.34E+08 | 0.38 | 0.02 | 2.16E+10 | 2.29E+09 | 0.22 | 0.02 |
| | newHRS+DSlargeU(60cmConc)+4inDonut | 1.15E+10 | 4.18E+08 | 0.38 | 0.01 | 2.39E+10 | 2.67E+09 | 0.25 | 0.03 |
| CREX 5 | NewHRSDet | 2.72E+10 | 1.29E+09 | 0.89 | 0.04 | 5.21E+10 | 7.38E+09 | 0.54 | 0.08 |
| | newHRSDet+fatPipe+prex2End | 4.06E+09 | 3.68E+08 | 0.13 | 0.01 | 1.15E+10 | 2.38E+09 | 0.12 | 0.02 |
| | newHRS+sideShield(31cmConc) + 4inDonut | 3.15E+09 | 3.56E+08 | 0.10 | 0.01 | 3.10E+10 | 5.44E+09 | 0.32 | 0.06 |
| | newHRS+DSlargeU(30cmConc)+4inDonut | 5.54E+09 | 4.47E+08 | 0.18 | 0.01 | 1.20E+10 | 2.67E+09 | 0.12 | 0.03 |
| | newHRS+DSlargeU(45cmConc)+4inDonut | 5.26E+09 | 4.35E+08 | 0.17 | 0.01 | 9.55E+09 | 1.81E+09 | 0.10 | 0.02 |
| | newHRS+DSlargeU(60cmConc)+4inDonut | 4.80E+09 | 4.05E+08 | 0.16 | 0.01 | 1.05E+10 | 1.98E+09 | 0.11 | 0.02 |

- Shielding the HRS alone produces the best results when we consider both PREX and CREX
  - however if we look at the flow meter detector we can see that it could still use local shielding itself
- Increasing the donut hole to 4in (10.13 cm) solves most of the problems we see during CREX
- The 45 cm U shaped dump shielding can bring us to an overall (PREX2 + CREX) radiation level of 45% of PREX1 (in the ERR we promised 25% of PREX 1)

# Conclusions

- The detailed dump simulation indicates that we will have (before mitigation) a slightly higher radiation level inside the hall compared with what was presented at the ERR
  - To fix most of the radiation issue for CREX we propose and increase the donut hole to at least 4 in (10.13 cm)
  - For PREX additional shielding is needed and we determined that a 45 cm thick U shaped wall around the beam pipe, approximately 2 meters in front of the dump is our most efficient configuration (after looking at different configurations and shielding materials)
  - This shielding will weight approximately 8-11 tonnes (considering a density of 1750-2400 kg/m3 for concrete )

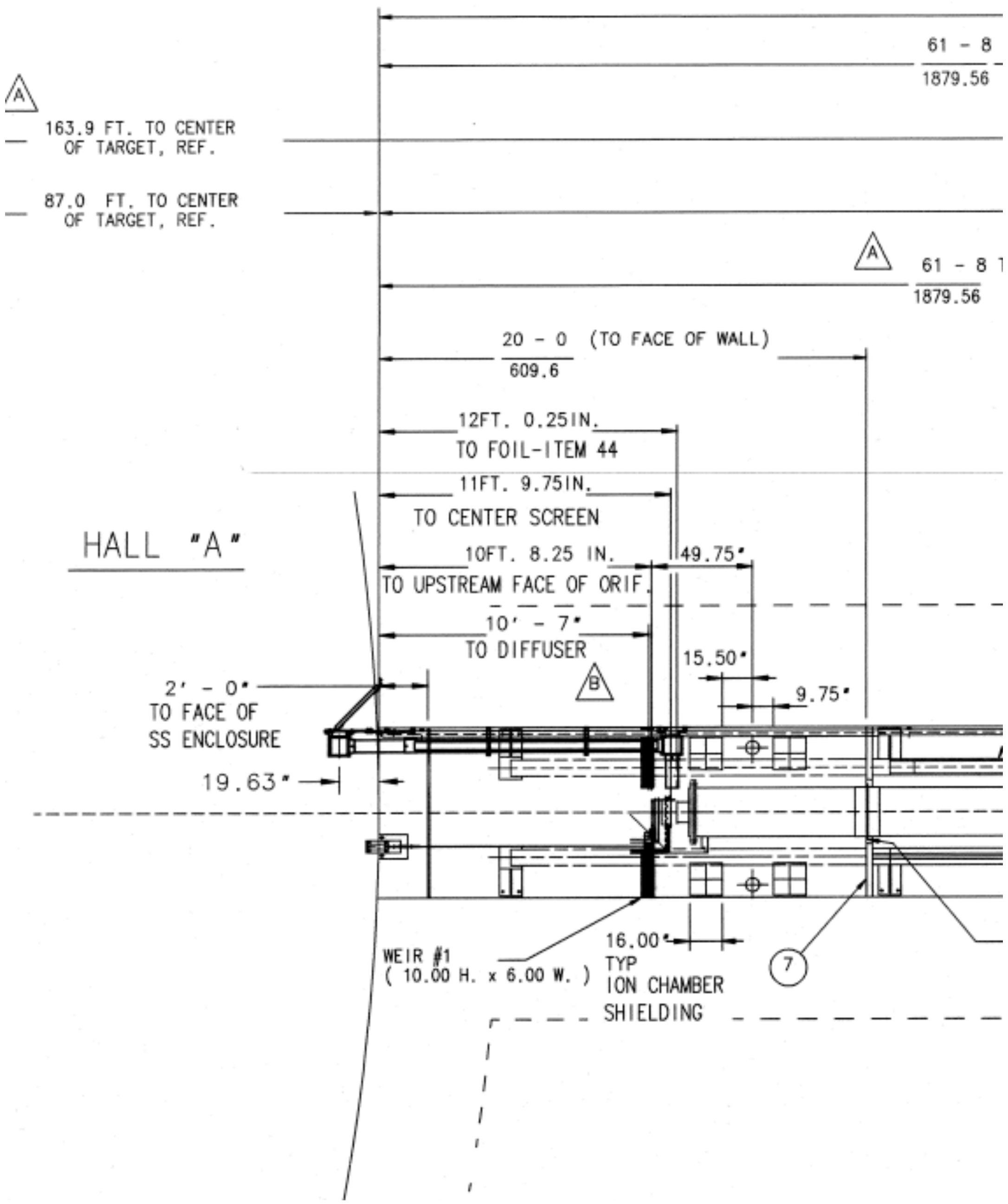
# Q1 steel pipe comparison

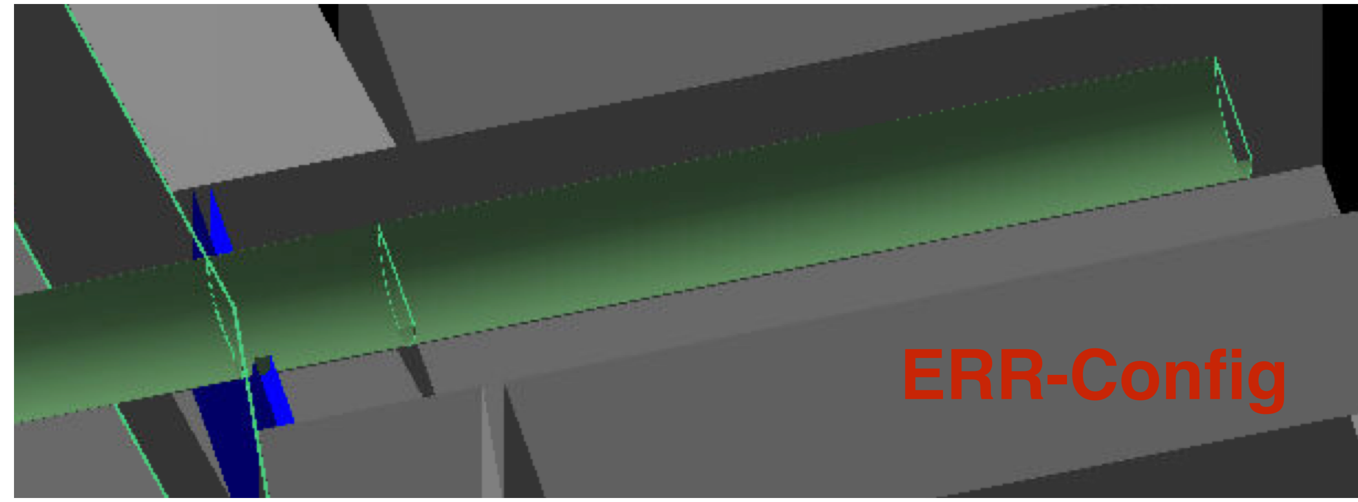


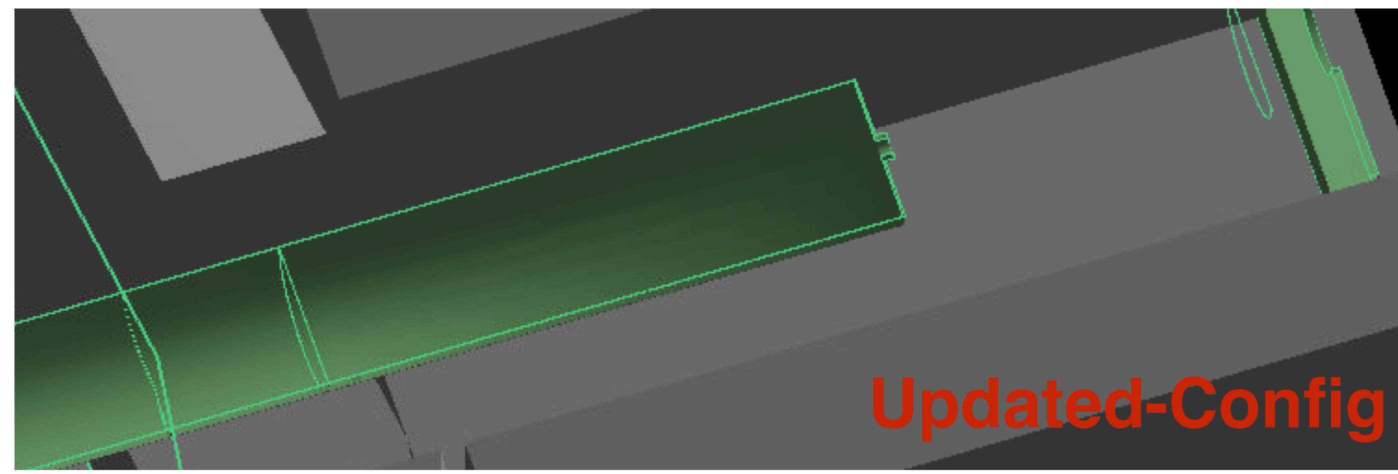

- We replaced the Al telescoping pipe (the part until the 8in gate valve) with stainless steel (the difference to carbon-steel should be minimal in terms to radiation)
- We took a look at the important detectors inside the simulation and calculate the NEIL value per electron on target for each
- We conclude that there is only a minimal increase in radiation close to septum (~10% for both PREX and CREX), while the rest of the detectors don't see statistically relevant increases

# PREX 1 radiation estimation

**Hall A dump configuration from Keith W. for 2010:**



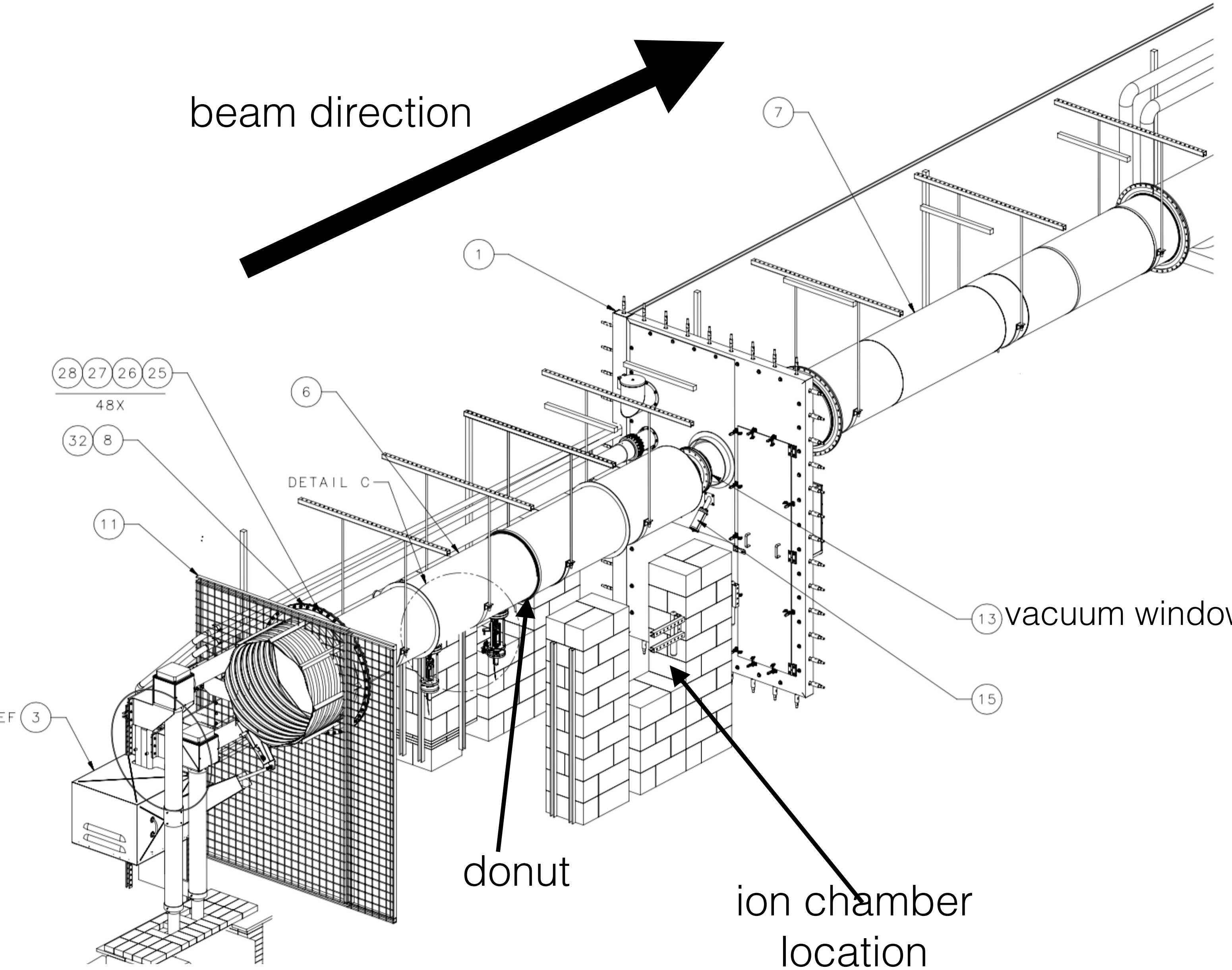



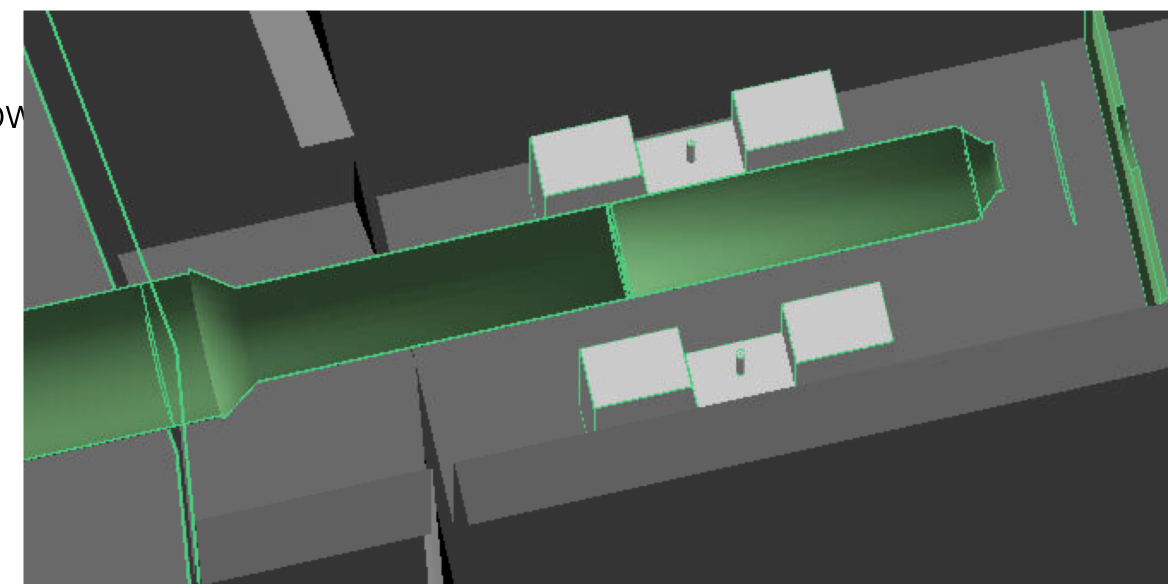

| | ERR | Update |
|---|---|---|
| HRS rad [NEIL/cm2] | 2.3E+11 | 2.1E+11 |

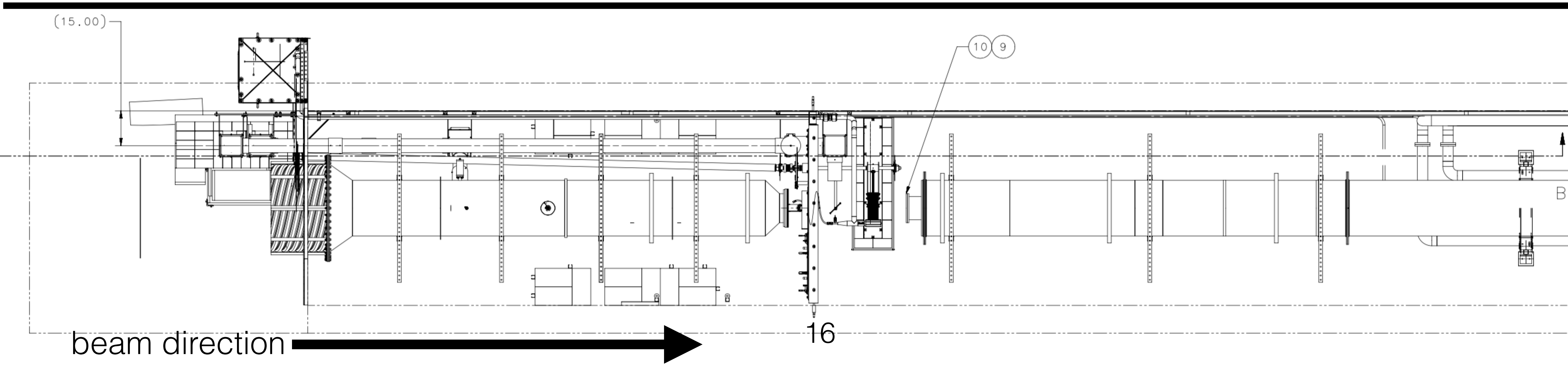
- PREX 1 estimates were done with a rudimentary dump configuration (most of the radiation to electronics came from within the hall proper)
    - The splash back from the dump was simulated by putting a stainless steel wall at the entrance of the dump tunnel
- The updated configuration with 2in aperture and the Al wall produced similar levels of radiation to the HRS platform

# Current Hall A Dump configuration



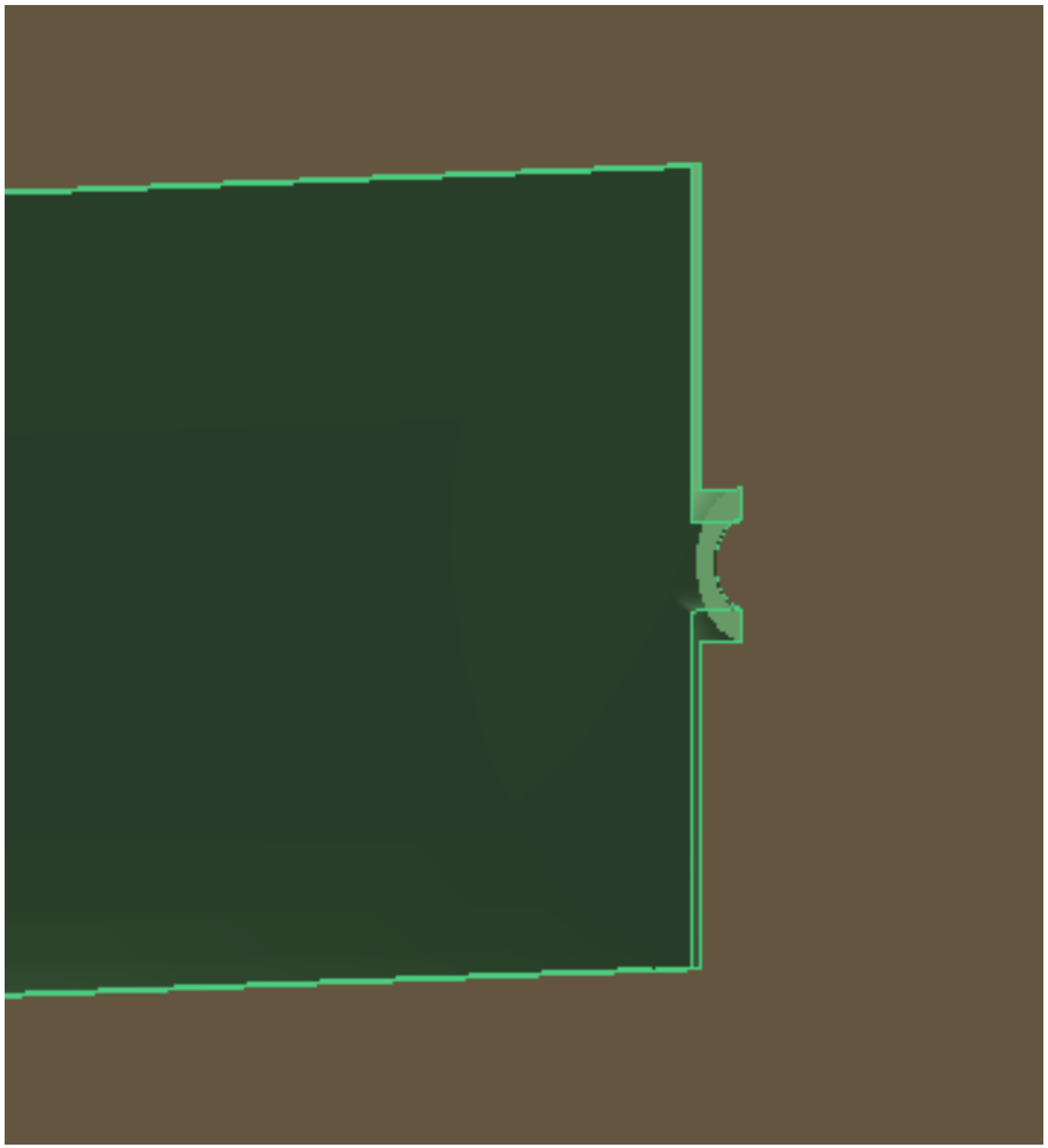

- For PREX2/CREX we will not need to use the diffuser
- We implemented the major features of the current design in the simulation
  - including the 4 cm Al aperture at ~midway until the Al door



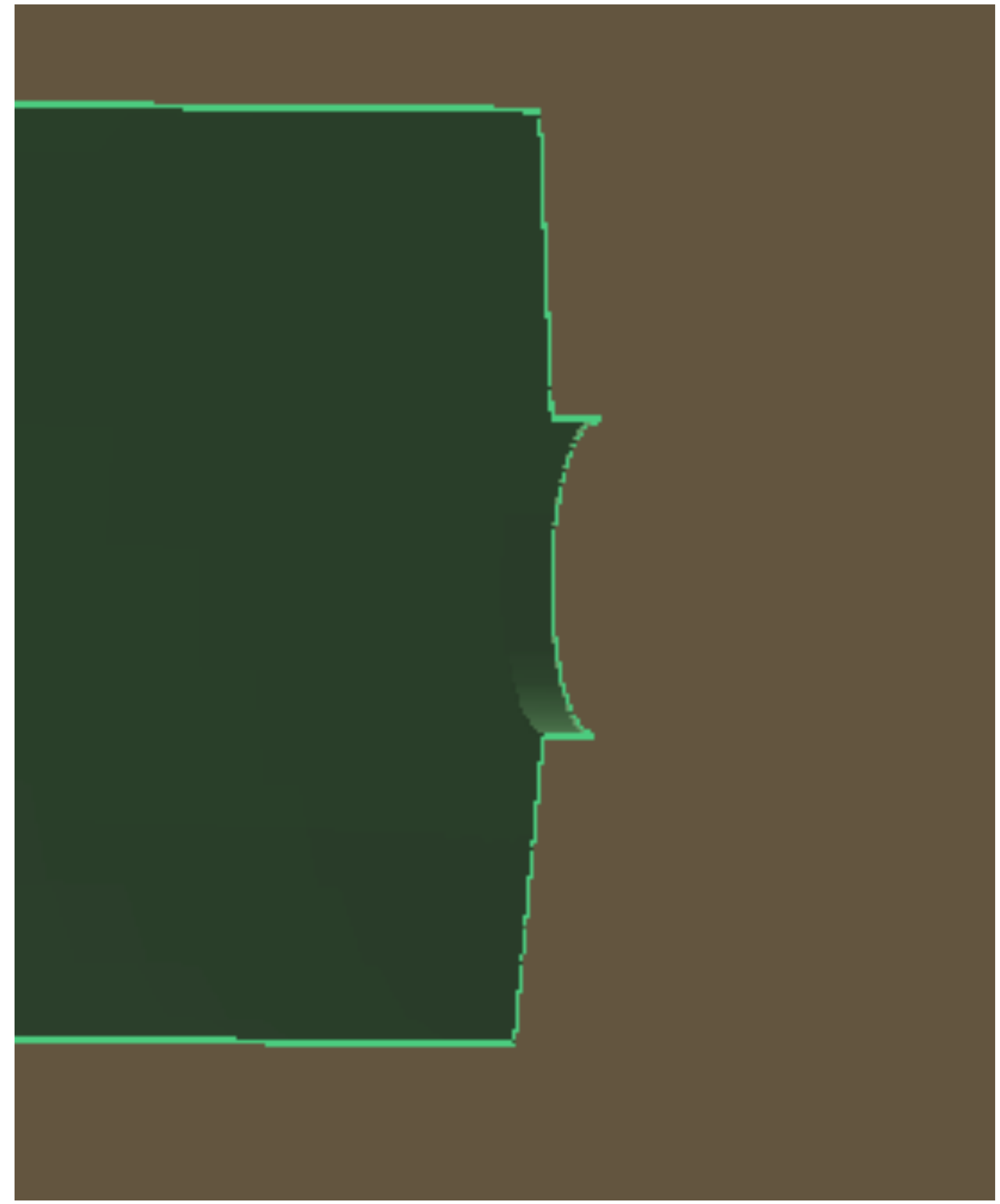


# PREX2 fat pipe

## PREX1 style pipe end



## PREX2 style pipe end

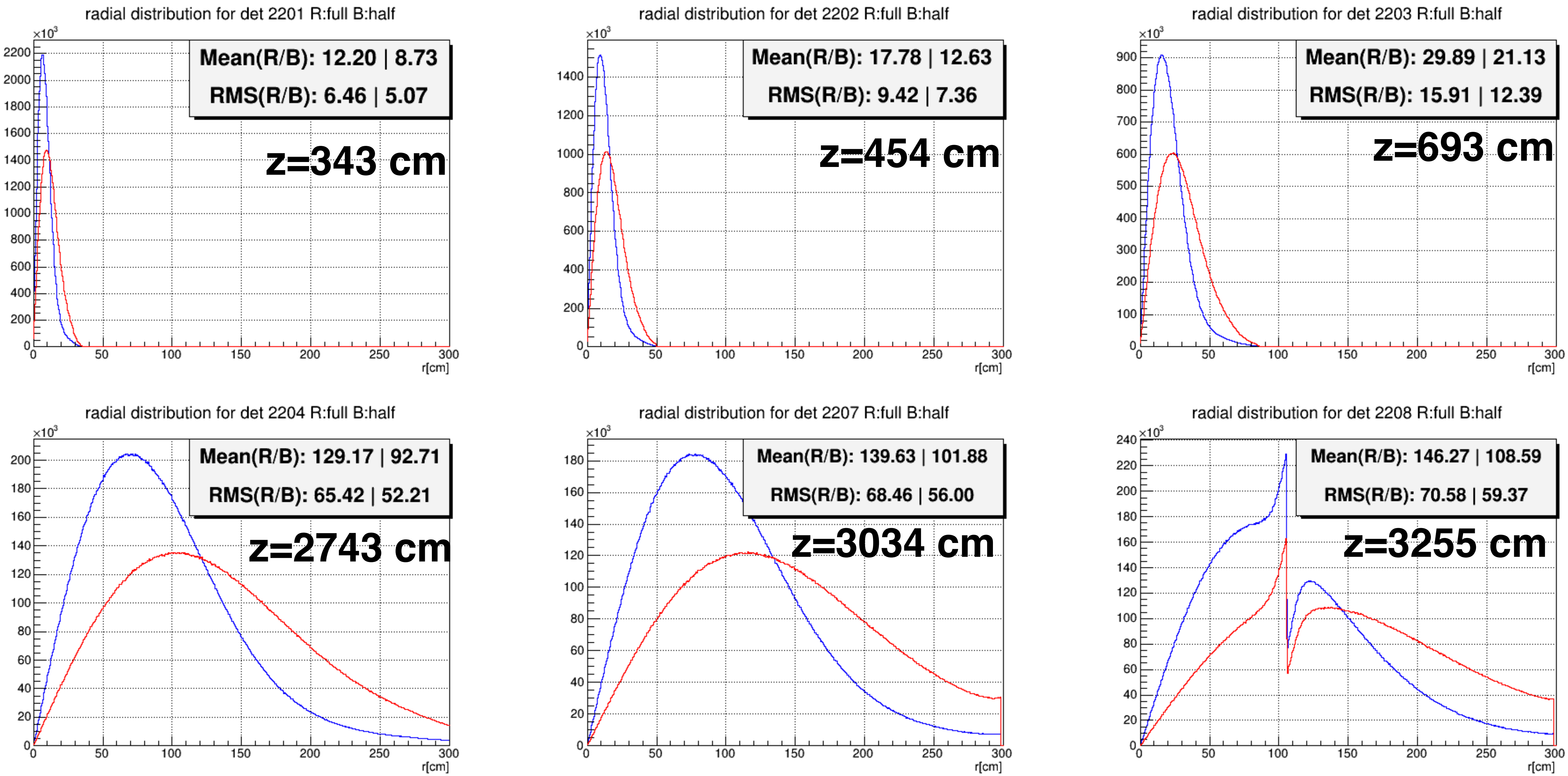


# PREX target thickness

| | HRS detector | | | | Under detector | | | |
|---|---|---|---|---|---|---|---|---|
| | Total NEIL/cm2 | uncert | Ratio to P1 | uncert | Total NEIL/cm2 | uncert | Ratio to P1 | uncert |
| newHRS+halfLead target+4inDonut | 1.91E+10 | 8.60E+08 | 0.41 | 0.02 | 3.53E+10 | 4.72E+09 | 0.48 | 0.07 |
| newHRSDet+fullLead+4inDonut | 2.88E+10 | 7.36E+08 | 0.63 | 0.03 | 7.50E+10 | 5.14E+09 | 1.01 | 0.10 |
| newHRSDet+fullLead | 3.08E+10 | 7.62E+08 | 0.67 | 0.03 | 6.88E+10 | 4.84E+09 | 0.93 | 0.09 |
| newHRSDet+75%Lead | 2.67E+10 | 8.38E+08 | 0.58 | 0.03 | 5.65E+10 | 5.00E+09 | 0.76 | 0.08 |
| newHRS+halfLead target | 2.64E+10 | 1.03E+09 | 0.57 | 0.03 | 6.30E+10 | 6.87E+09 | 0.85 | 0.11 |
| | | | | | | | | |
| newHRS+DSlargeU(45cmH2O)+4inDonut | 1.08E+10 | 4.04E+08 | 0.23 | 0.01 | 2.22E+10 | 2.47E+09 | 0.30 | 0.04 |

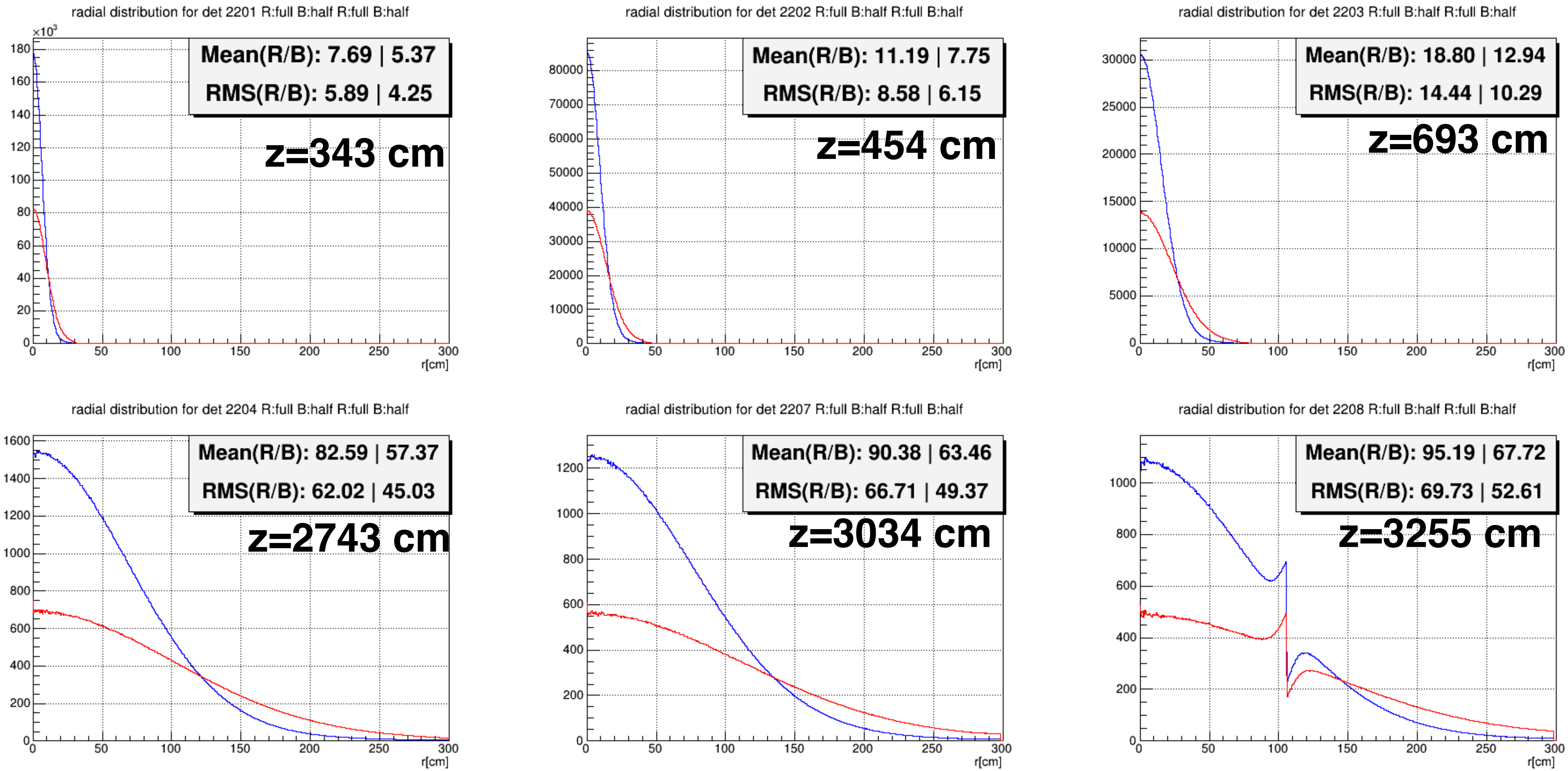
- Scaled each simulation with (1/targetThickness)
- The reduction in radiation due to target thickness is not as effective as shielding
- I am investigating the large difference between halfTarget and halfTarge+4inDonut
  - it would seem that we get some benefit from going to 75% but it levels off and we get the same benefit for going to 50%

# Half target analysis - radial distributions




- Radial distributions of primary electrons as they pass vacuum detector at different z positions away from the target

# Half target analysis - radial distributions



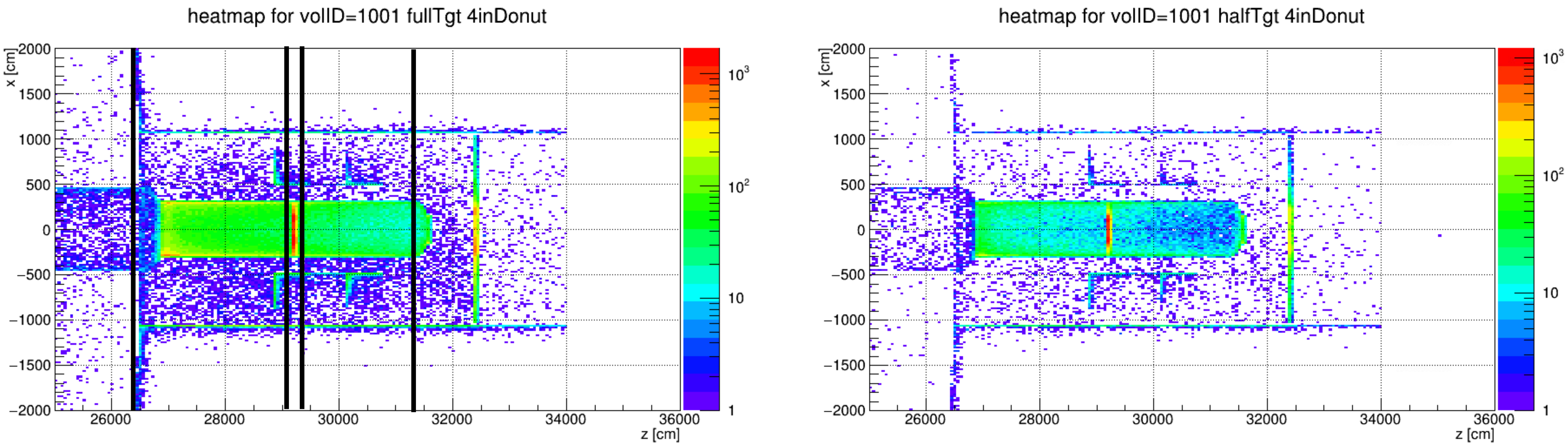

- Radial distributions of primary electrons as they pass vacuum detector at different z positions away from the target (with area taken out)

# Half target analysis - radial distributions

| z position [cm] | full tgt (half width mm) | half tgt (half width mm) | full tgt (rad) | half tgt (rad) | full tgt (deg) | half tgt (deg) |
|---|---|---|---|---|---|---|
| 343 | 5.89 | 4.25 | 0.00343 | 0.00248 | 0.20 | 0.14 |
| 454 | 8.58 | 6.15 | 0.00378 | 0.00271 | 0.22 | 0.16 |
| 693 | 14.44 | 10.29 | 0.00417 | 0.00297 | 0.24 | 0.17 |
| 2743 | 62.02 | 45.03 | 0.00452 | 0.00328 | 0.26 | 0.19 |
| 3034 | 66.71 | 48.37 | 0.00440 | 0.00319 | 0.25 | 0.18 |
| | | | | | | |
| | | | MSc width (rad) | MSc width (deg) | | |
| | | 5% | 0.00269 | 0.15440 | | |
| | | 10% | 0.00392 | 0.22485 | | |

- Taking the widths from the previous slide and looking at the Molliere multiple scattering formula we can see that (at least for the first few detectors) the angular deviations seem to be well described

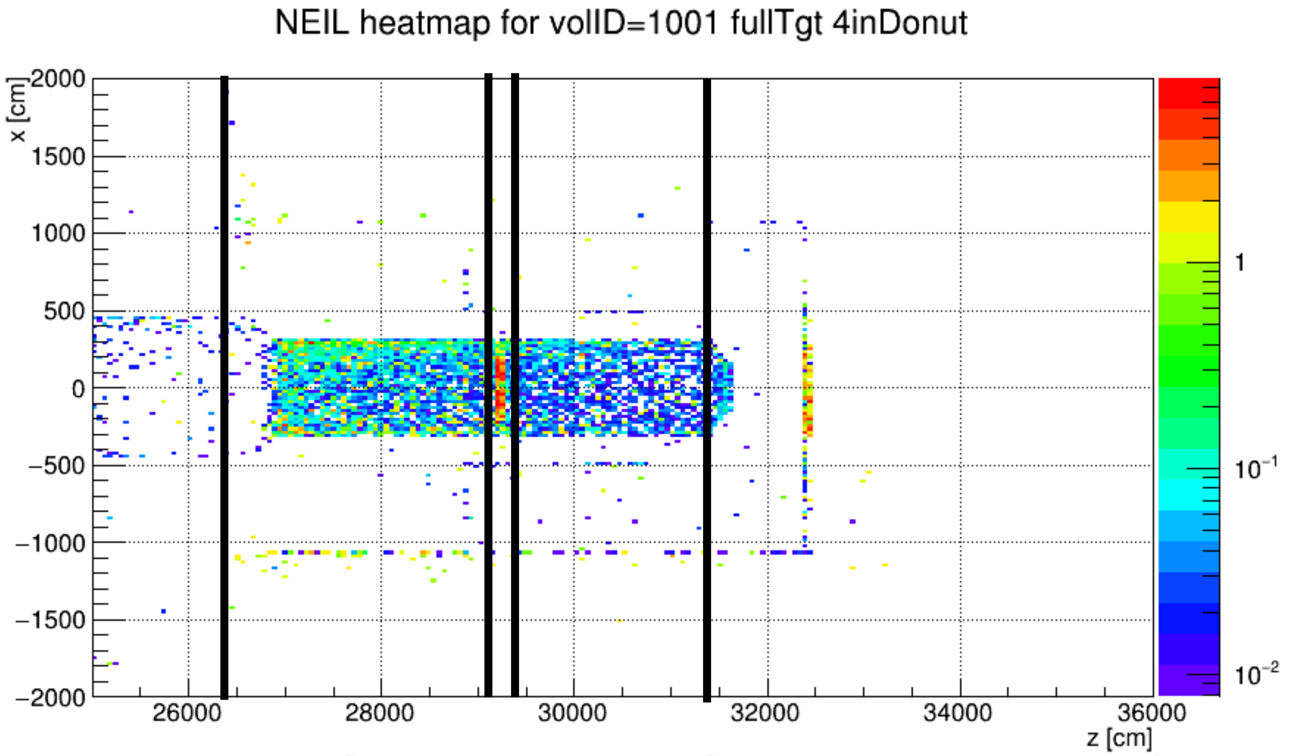
# Half target analysis - counts

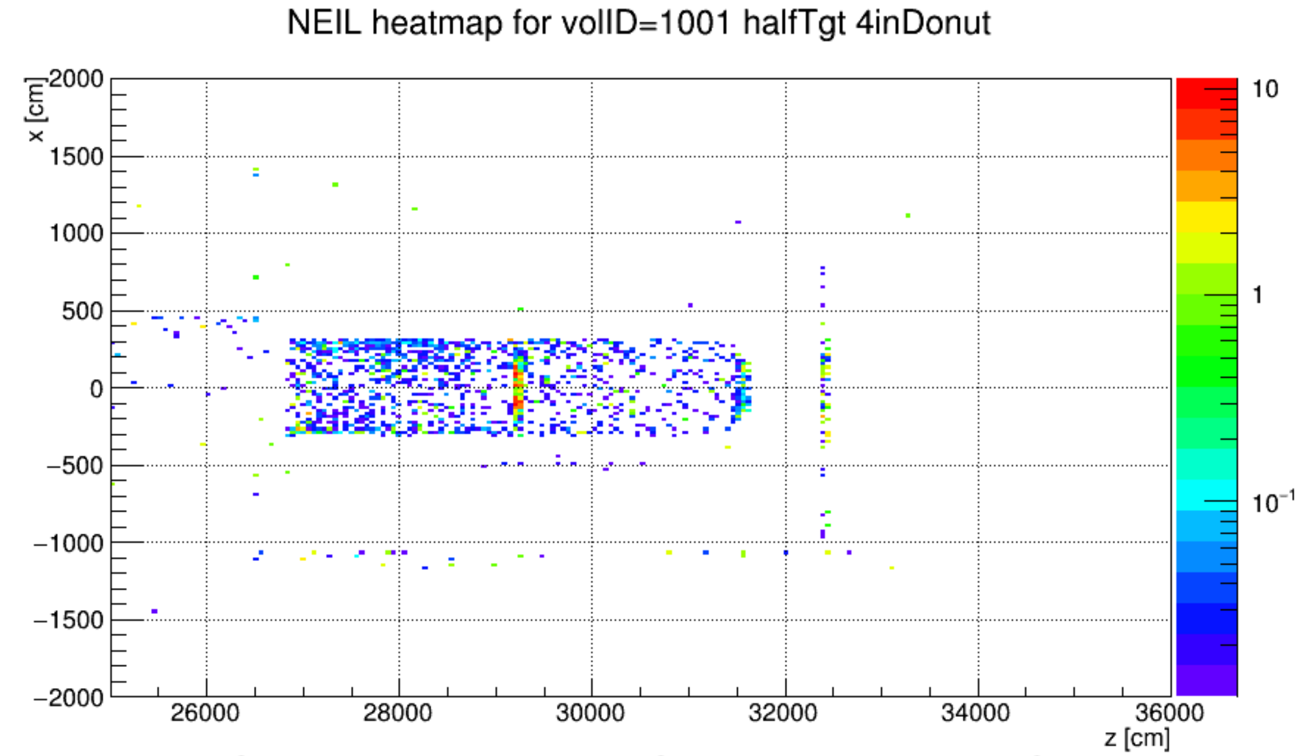



| | R1(25 to 26.4) | R2 (26.4 to 29.15) | R3 (29.15 to 29.3) | R4 (29.3 to 31.4) | R5 (31.4 to 36) | Sum |
|---|---|---|---|---|---|---|
| full tgt | 2801 | 126190 | 42991 | 51490 | 34609 | 258081 |
| half tgt | 804 | 29822 | 21462 | 14135 | 13117 | 79340 |
| full tgt | 1% | 49% | 17% | 20% | 13% | Ratio |
| half tgt | 1% | 38% | 27% | 18% | 17% | 31% |

- Look at events from 5e7 electrons on target
- Counts are energies larger 0.1 MeV

# Half target analysis - NEIL




| | R1(25 to 26.4) | R2 (26.4 to 29.15) | R3 (29.15 to 29.3) | R4 (29.3 to 31.4) | R5 (31.4 to 36) | Sum |
|---|---|---|---|---|---|---|
| full tgt | 21.9978 | 471.863 | 192.761 | 160.339 | 141.427 | 988.3878 |
| half tgt | 8.91172 | 107.461 | 132.21 | 44.2156 | 57.0149 | 349.81322 |
| full tgt | 2% | 48% | 20% | 16% | 14% | Ratio |
| half tgt | 3% | 31% | 38% | 13% | 16% | 35% |

- Look at events from 5e7 electrons on target
- Counts are energies larger 0.1 MeV
- Most of the NEIL is reduces in the beam pipe before the donut

# PREX radiation all studies

| | | HRS detector | | | | Under detector | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total NEIL/cm2 | uncert | Ratio to P1 | uncert | Total NEIL/cm2 | uncert | Ratio to P1 | uncert |
| | PREX1 (ERR dump) | 4.60E+10 | 1.79E+09 | 1.00 | 0.06 | 7.43E+10 | 4.92E+09 | 1.00 | 0.09 |
| | PREX2 current | 5.77E+10 | 5.69E+09 | 1.25 | 0.13 | 7.60E+10 | 1.85E+10 | 1.02 | 0.26 |
| | C5 current | 3.86E+10 | 7.80E+09 | 0.84 | 0.17 | 4.70E+10 | 1.96E+10 | 0.63 | 0.27 |
| PREX 2 | current (farm) | 5.23E+10 | 1.11E+09 | 1.14 | 0.05 | 8.03E+10 | 3.77E+09 | 1.08 | 0.09 |
| | vacuum beamline | 5.12E+10 | 1.55E+09 | 1.11 | 0.05 | 8.06E+10 | 5.34E+09 | 1.09 | 0.10 |
| | no donut | 3.90E+10 | 1.31E+09 | 0.85 | 0.04 | 5.04E+10 | 3.74E+09 | 0.68 | 0.07 |
| | smaller Coll Neck | 4.38E+10 | 1.02E+09 | 0.95 | 0.04 | 6.92E+10 | 3.19E+09 | 0.93 | 0.08 |
| | smaller Coll Pipe2Donut | 4.17E+10 | 9.59E+08 | 0.91 | 0.04 | 7.68E+10 | 3.29E+09 | 1.03 | 0.08 |
| | smaller Coll MidDonut | 5.77E+10 | 9.57E+08 | 1.25 | 0.05 | 1.21E+11 | 3.50E+09 | 1.63 | 0.12 |
| | larger Hall | 5.46E+10 | 1.63E+09 | 1.19 | 0.06 | 8.00E+10 | 5.32E+09 | 1.08 | 0.10 |
| | new HRS | 3.00E+10 | 1.45E+09 | 0.65 | 0.04 | 8.12E+10 | 5.42E+09 | 1.09 | 0.10 |
| | New HRS + 2ft Iron | 2.07E+10 | 1.17E+09 | 0.45 | 0.03 | 2.97E+10 | 2.81E+09 | 0.40 | 0.05 |
| | NewHRSDet | 3.05E+10 | 7.62E+08 | 0.66 | 0.03 | 7.09E+10 | 4.98E+09 | 0.95 | 0.09 |
| | NewHRSDet+2ft Fe | 1.79E+10 | 5.39E+08 | 0.39 | 0.02 | 2.32E+10 | 2.44E+09 | 0.31 | 0.04 |
| | NewHRSDet+2ft Conc | 1.55E+10 | 5.00E+08 | 0.34 | 0.02 | 2.23E+10 | 2.29E+09 | 0.30 | 0.04 |
| | NewHRSDet+1ftConc1ftFe | 6.79E+09 | 1.95E+09 | 0.15 | 0.04 | N/A | N/A | #VALUE! | #VALUE! |
| | NewHRSDet+1ftConc1ftFe+4inDonut | 1.46E+10 | 4.81E+08 | 0.32 | 0.02 | 1.91E+10 | 1.94E+09 | 0.26 | 0.03 |
| | newHRSDet+fat Pipe | 1.07E+10 | 4.10E+08 | 0.23 | 0.01 | 3.23E+10 | 3.18E+09 | 0.43 | 0.05 |
| | newHRSDet+fatPipe+prex2End | 7.29E+09 | 2.88E+08 | 0.16 | 0.01 | 2.18E+10 | 2.43E+09 | 0.29 | 0.04 |
| | newHRSDet+sideShield (1ftConc) | 9.81E+09 | 4.33E+08 | 0.21 | 0.01 | 6.66E+10 | 4.75E+09 | 0.90 | 0.09 |
| | newHRS+sideShield(31cmConc) + 4inDonut | 9.72E+09 | 4.36E+08 | 0.21 | 0.01 | 5.90E+10 | 4.49E+09 | 0.79 | 0.08 |
| | newHRS+DStopCover(75cmConc)+4inDonut | 1.03E+10 | 3.80E+08 | 0.22 | 0.01 | 1.88E+10 | 2.13E+09 | 0.25 | 0.03 |
| | newHRS+DSlargeU(75cmConc)+4inDonut | 1.11E+10 | 4.14E+08 | 0.24 | 0.01 | 2.20E+10 | 2.42E+09 | 0.30 | 0.04 |
| | newHRS+DSlargeU(30cmConc)+4inDonut | 1.35E+10 | 4.67E+08 | 0.29 | 0.02 | 1.75E+10 | 2.04E+09 | 0.24 | 0.03 |
| | newHRS+DSlargeU(45cmConc)+4inDonut | 1.18E+10 | 4.34E+08 | 0.26 | 0.01 | 2.16E+10 | 2.29E+09 | 0.29 | 0.04 |
| | newHRS+DSlargeU(60cmConc)+4inDonut | 1.15E+10 | 4.18E+08 | 0.25 | 0.01 | 2.39E+10 | 2.67E+09 | 0.32 | 0.04 |
| | newHRS+halfLead target+4inDonut | 9.54E+09 | 4.30E+08 | 0.21 | 0.01 | 1.76E+10 | 2.36E+09 | 0.24 | 0.04 |
| | newHRS+DSlargeU(45cmH2O)+4inDonut | 1.08E+10 | 4.04E+08 | 0.23 | 0.01 | 2.22E+10 | 2.47E+09 | 0.30 | 0.04 |
| | newHRS+sideShield(31cmConc) + 4inDonut == Hall Only | 5.12E+09 | 3.03E+08 | 0.11 | 0.01 | 1.39E+10 | 1.58E+09 | 0.19 | 0.02 |
| | newHRS+DStopCover(75cmConc)+4inDonut == Hall only | 7.20E+09 | 2.96E+08 | 0.16 | 0.01 | 1.46E+10 | 1.71E+09 | 0.20 | 0.03 |
| | newHRS+DSlargeU(75cmConc)+4inDonut == Hall only | 7.30E+09 | 3.10E+08 | 0.16 | 0.01 | 1.33E+10 | 1.39E+09 | 0.18 | 0.02 |

# CREX radiation all studies

| | | HRS detector | | | | Under detector | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Total NEIL/cm2 | uncert | Ratio to P1 | uncert | Total NEIL/cm2 | uncert | Ratio to P1 | uncert |
| | PREX1 (ERR dump) | 4.60E+10 | 1.79E+09 | 1.00 | 0.06 | 7.43E+10 | 4.92E+09 | 1.00 | 0.09 |
| CREX 5 | current (farm) | 4.47E+10 | 1.84E+09 | 0.97 | 0.06 | 5.78E+10 | 5.41E+09 | 0.78 | 0.09 |
| | vacuum beamline | 4.01E+10 | 2.50E+09 | 0.87 | 0.06 | 7.14E+10 | 8.97E+09 | 0.96 | 0.14 |
| | no donut | 1.37E+10 | 1.20E+09 | 0.30 | 0.03 | 2.29E+10 | 4.73E+09 | 0.31 | 0.07 |
| | smaller Coll Neck | 3.91E+10 | 1.77E+09 | 0.85 | 0.05 | 6.03E+10 | 5.70E+09 | 0.81 | 0.09 |
| | smaller Coll Pipe2Donut | 3.59E+10 | 1.65E+09 | 0.78 | 0.05 | 5.86E+10 | 5.46E+09 | 0.79 | 0.09 |
| | smaller Coll MidDonut | 1.50E+11 | 2.53E+09 | 3.26 | 0.14 | 2.84E+11 | 8.31E+09 | 3.83 | 0.28 |
| | larger Hall | 4.05E+10 | 2.53E+09 | 0.88 | 0.06 | 6.48E+10 | 8.34E+09 | 0.87 | 0.13 |
| | new HRS | 2.09E+10 | 2.04E+09 | 0.45 | 0.05 | 5.92E+10 | 7.85E+09 | 0.80 | 0.12 |
| | New HRS + 2ft Iron | 1.54E+10 | 1.76E+09 | 0.34 | 0.04 | 1.42E+10 | 3.21E+09 | 0.19 | 0.05 |
| | NewHRSDet | 2.72E+10 | 1.29E+09 | 0.59 | 0.04 | 5.21E+10 | 7.38E+09 | 0.70 | 0.11 |
| | NewHRSDet+2ft Fe | 1.37E+10 | 8.34E+08 | 0.30 | 0.02 | 1.76E+10 | 3.37E+09 | 0.24 | 0.05 |
| | NewHRSDet+2ft Conc | 1.15E+10 | 7.72E+08 | 0.25 | 0.02 | 1.17E+10 | 3.24E+09 | 0.16 | 0.04 |
| | NewHRSDet+1ftConc1ftFe | 5.86E+09 | 2.46E+09 | 0.13 | 0.05 | N/A | N/A | #VALUE! | #VALUE! |
| | NewHRSDet+1ftConc1ftFe+4inDonut | 5.57E+09 | 4.21E+08 | 0.12 | 0.01 | 1.36E+10 | 2.75E+09 | 0.18 | 0.04 |
| | newHRSDet+fat Pipe | 2.70E+10 | 1.26E+09 | 0.59 | 0.04 | 9.70E+10 | 1.08E+10 | 1.31 | 0.17 |
| | newHRSDet+fatPipe+prex2End | 4.06E+09 | 3.68E+08 | 0.09 | 0.01 | 1.15E+10 | 2.38E+09 | 0.15 | 0.03 |
| | newHRSDet+sideShield (1ftConc) | 6.96E+09 | 6.19E+08 | 0.15 | 0.01 | 4.39E+10 | 6.83E+09 | 0.59 | 0.10 |
| | newHRS+sideShield(31cmConc) + 4inDonut | 3.15E+09 | 3.56E+08 | 0.07 | 0.01 | 3.10E+10 | 5.44E+09 | 0.42 | 0.08 |
| | newHRS+DStopCover(75cmConc)+4inDonut | 5.51E+09 | 4.62E+08 | 0.12 | 0.01 | 1.20E+10 | 2.28E+09 | 0.16 | 0.03 |
| | newHRS+DSlargeU(75cmConc)+4inDonut | 6.04E+09 | 4.72E+08 | 0.13 | 0.01 | 1.07E+10 | 2.18E+09 | 0.14 | 0.03 |
| | newHRS+DSlargeU(30cmConc)+4inDonut | 5.54E+09 | 4.47E+08 | 0.12 | 0.01 | 1.20E+10 | 2.67E+09 | 0.16 | 0.04 |
| | newHRS+DSlargeU(45cmConc)+4inDonut | 5.26E+09 | 4.35E+08 | 0.11 | 0.01 | 9.55E+09 | 1.81E+09 | 0.13 | 0.03 |
| | newHRS+DSlargeU(60cmConc)+4inDonut | 4.80E+09 | 4.05E+08 | 0.10 | 0.01 | 1.05E+10 | 1.98E+09 | 0.14 | 0.03 |
| | newHRS+DSlargeU(45cmH2O)+4inDonut | 4.36E+09 | 3.44E+08 | 0.09 | 0.01 | 1.11E+10 | 2.11E+09 | 0.15 | 0.03 |
| | newHRS+sideShield(31cmConc) + 4inDonut == Hall Only | 2.13E+09 | 2.65E+08 | 0.05 | 0.01 | 1.10E+10 | 2.43E+09 | 0.15 | 0.03 |
| | newHRS+DStopCover(75cmConc)+4inDonut == Hall only | 3.85E+09 | 3.18E+08 | 0.08 | 0.01 | 1.17E+10 | 2.28E+09 | 0.16 | 0.03 |
| | newHRS+DSlargeU(75cmConc)+4inDonut == Hall only | 4.57E+09 | 3.82E+08 | 0.10 | 0.01 | 1.05E+10 | 2.18E+09 | 0.14 | 0.03 |