Simulation overview and recommendations

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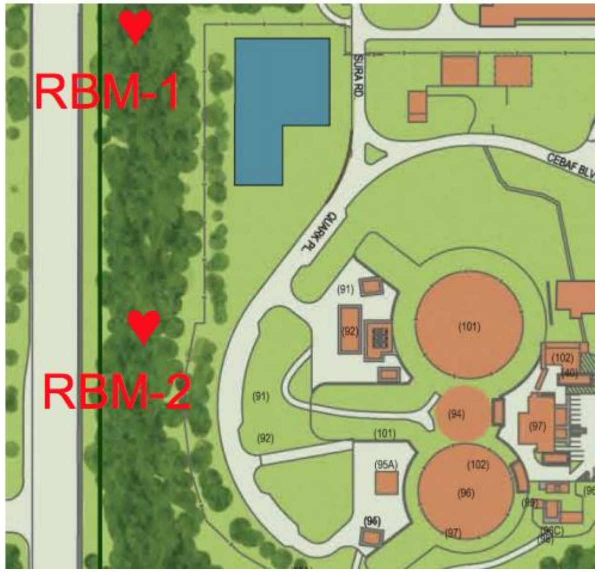
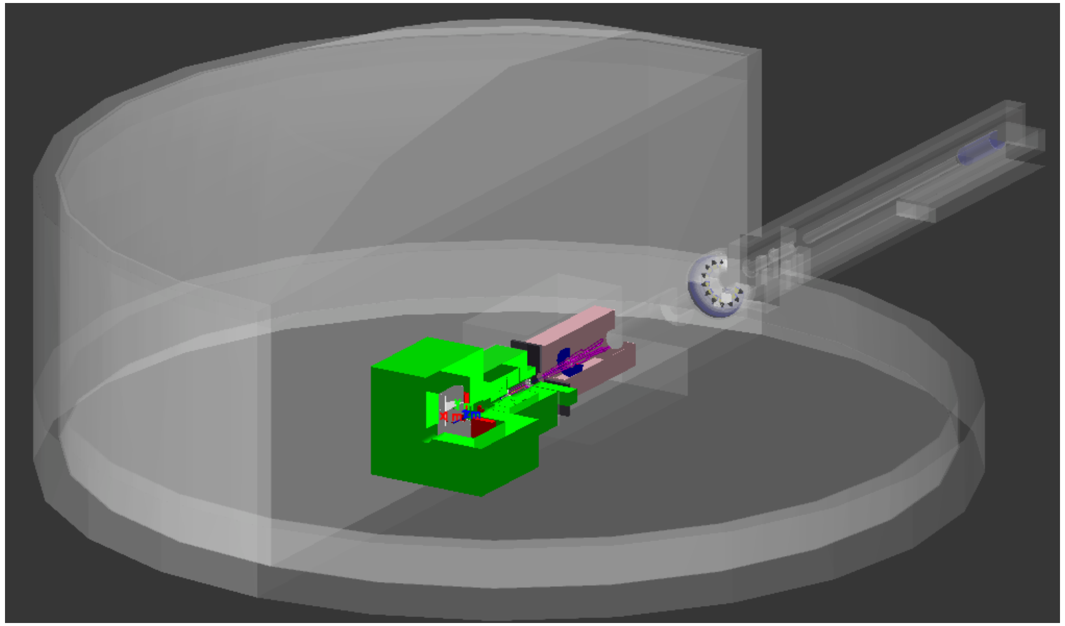
Introduction

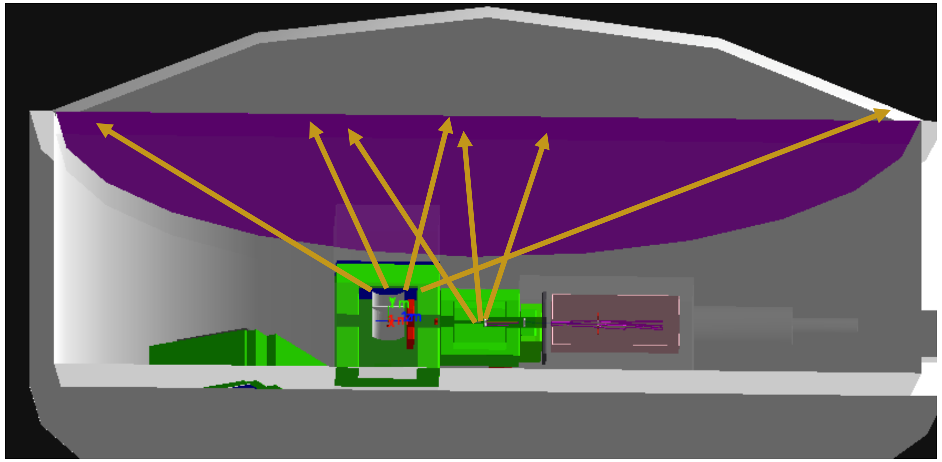


- Radiation measurements outside hall:
  - used for personnel protection
  - boundary dose limit imposed by DOE/Lab is 100/10 mrem per calendar year



- Radiation measurements inside hall:
  - used for equipment protection
  - needed to be able to make effective use of beam time
  - can be additional background

Boundary dose estimation



	current	Running time	charge on target
MOLLER	60uA	30 wks	585 C
PREX1	>50 uA	~8 wks	82 C

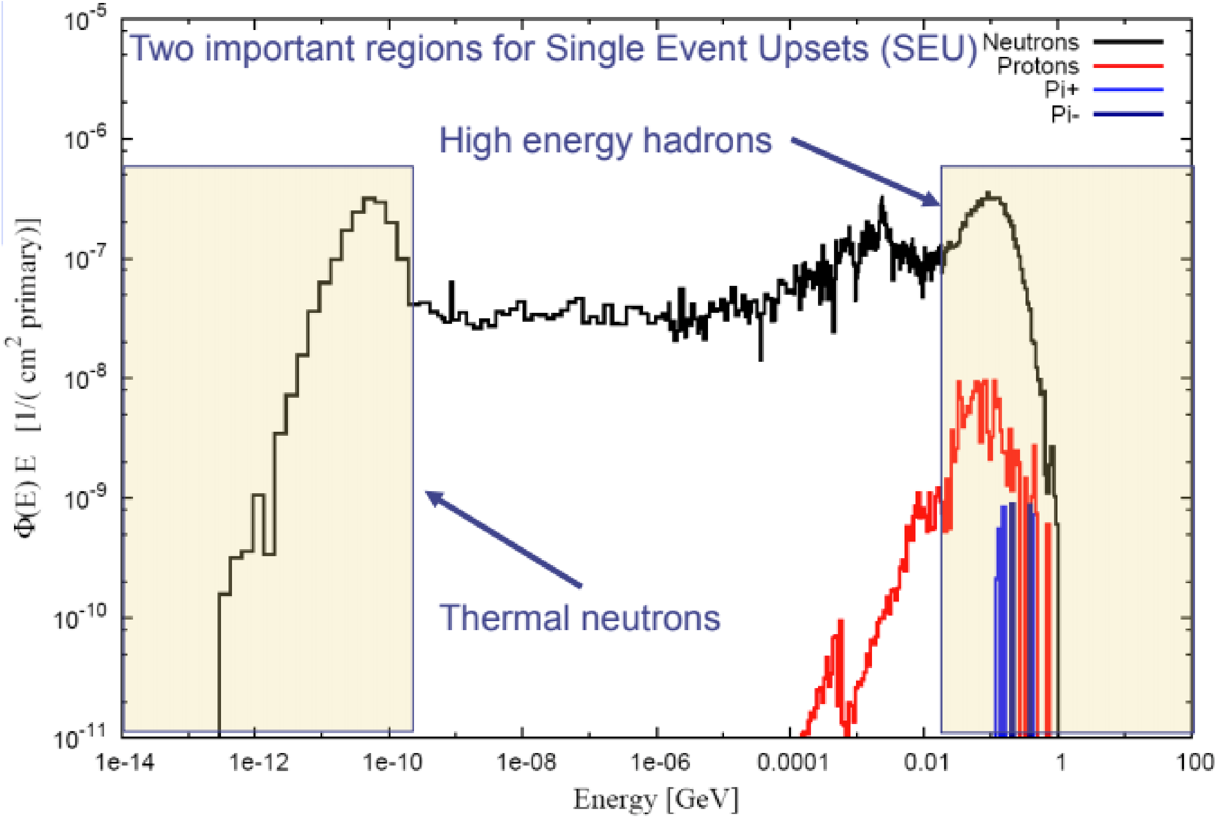
	mW/uA	boundry/yr
MOLLER	0.6	**2.4 mrem**
PREX1	2.4	**1.34 mrem**

- We evaluate the dose on the boundary by looking at high energy (E>30 MeV) neutrons reaching the roof of the hall
  - This has been shown by RadCon to be a good proxy
- We benchmark this proxy by simulating experimental configurations that produced significant (measurable) boundary dose
- We compare the HE neutron integrated power of previous experiment to different MOLLER configurations
  - This analysis will be strengthened by the PREX and CREX numbers
- The current shielding will allow MOLLER to remain under the JLab limit

Electronics damage

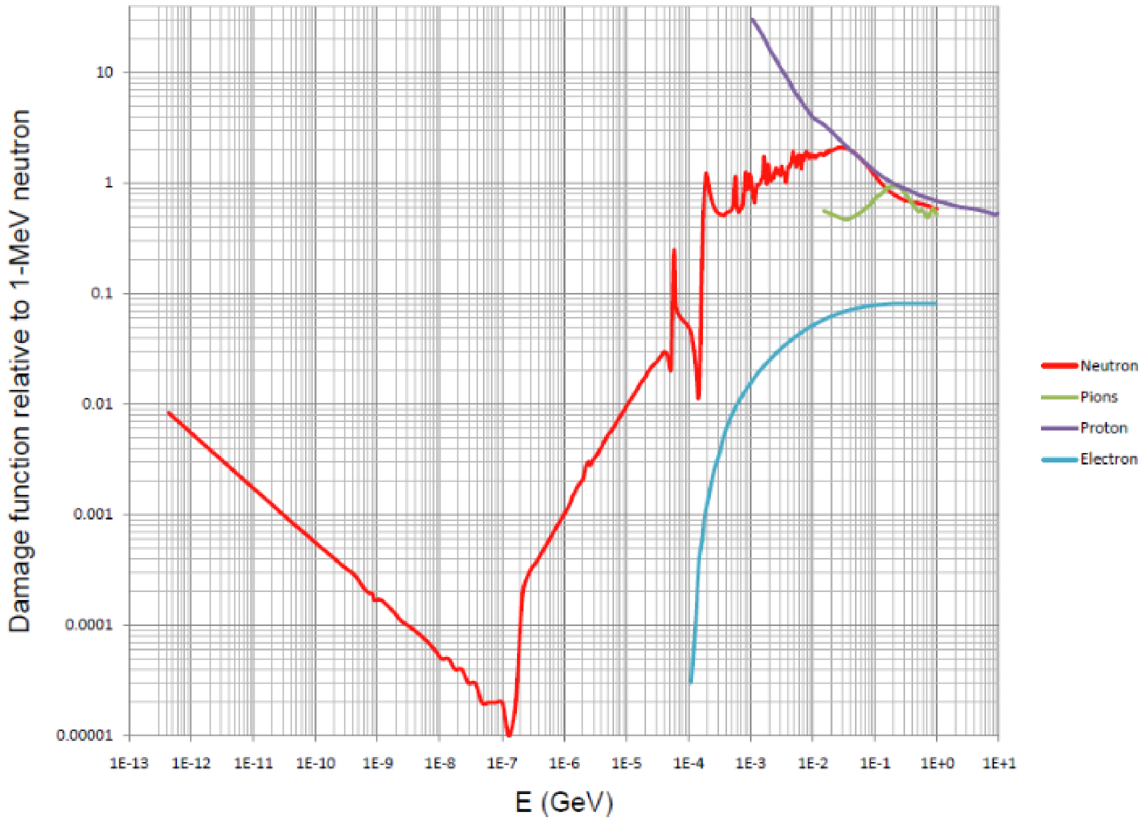
Category		Effect
Single Event effect (Random in time)	**Single Event Upset (SEU)**	Memory bit flip (soft error) Temporary functional failure
	Single Event Latchup (SEL)	Abnormally high current state Permanent/destructive if not protected
Cumulative effects (Long term)	**Total Ionizing Dose (TID)**	Charge build-up in oxide Threshold shift & increased leakage current Ultimately destructive
	Displacement damage	Atomic displacements Degradation over time Ultimately desctructive

Single event upsets



- We evaluate both the low energy (thermal) neutrons and the high energy hadron flux at locations where we have electronics
- We compare to fluxes simulated for experimental setups that ran successfully before at JLab

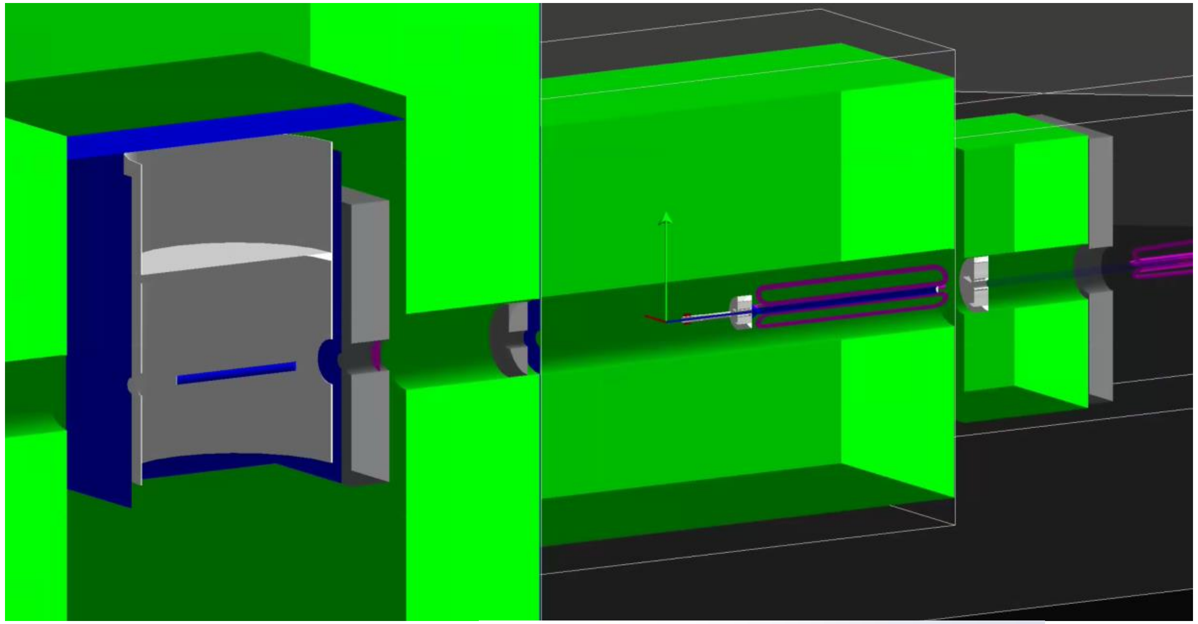
Permanent damage

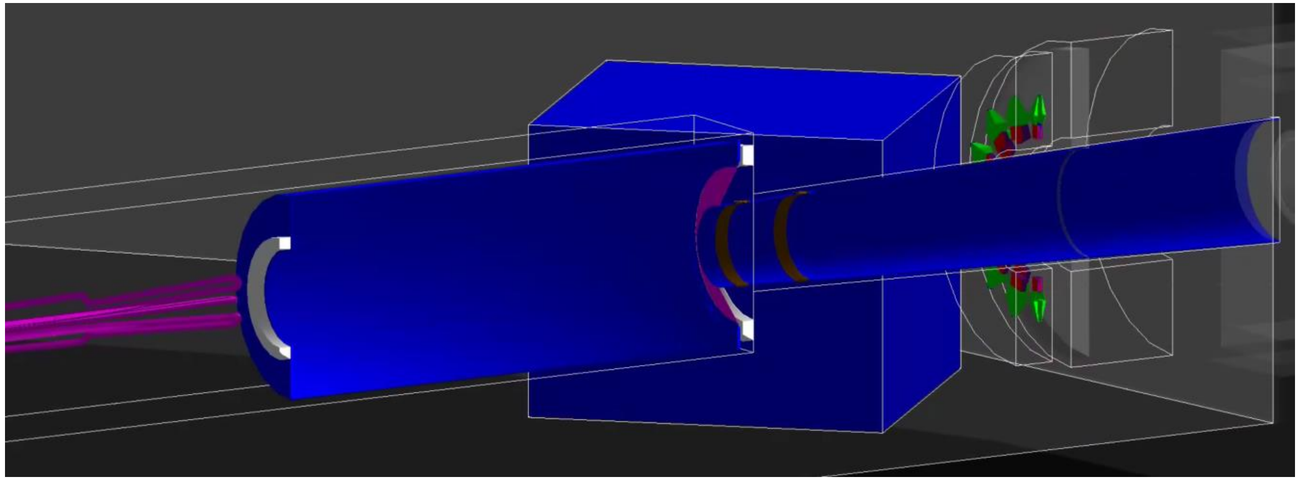


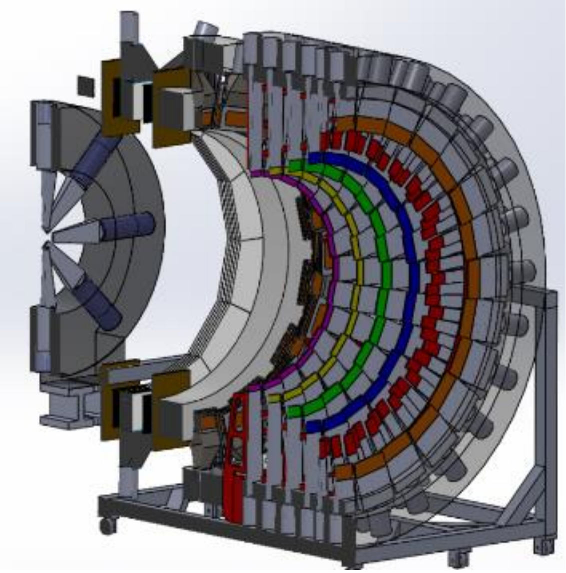
- We evaluate the entire spectrum for neutrons, pions, protons and electrons and use the FLUKA damage functions to convert them into 1-MeV neutron equivalent damage
- Typical commercial semiconductor electronics will show signs of damage at ~1E13 1-MeV n/cm^2

Current geometry

- The maximal shielding upstream of the hybrid we had in the previous review has remained the same
  - Target: 1.4 m of concrete on 5 sides; 40 cm thick Pb shield
  - Collimator 1&2: 1.5 m concrete all around in phi
  - Collimator 4: 1m concrete all around in phi; 25cm Pb shield wall
- US(Target) vacuum window has been optimized and placed right DS of the target
- We have minimized the amount of Vacuum we have in the hall to only beamline regions to allow for showering in the air in the rest of the hall
- Drift pipe, collars, detector pipe as well as shower max and pion Pb doughnut



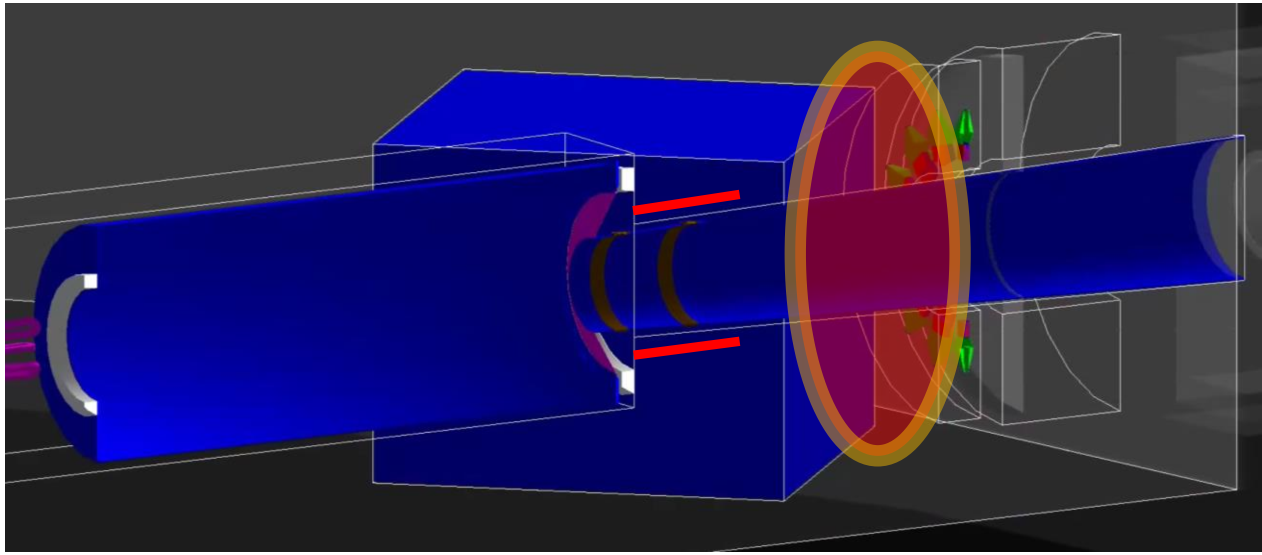


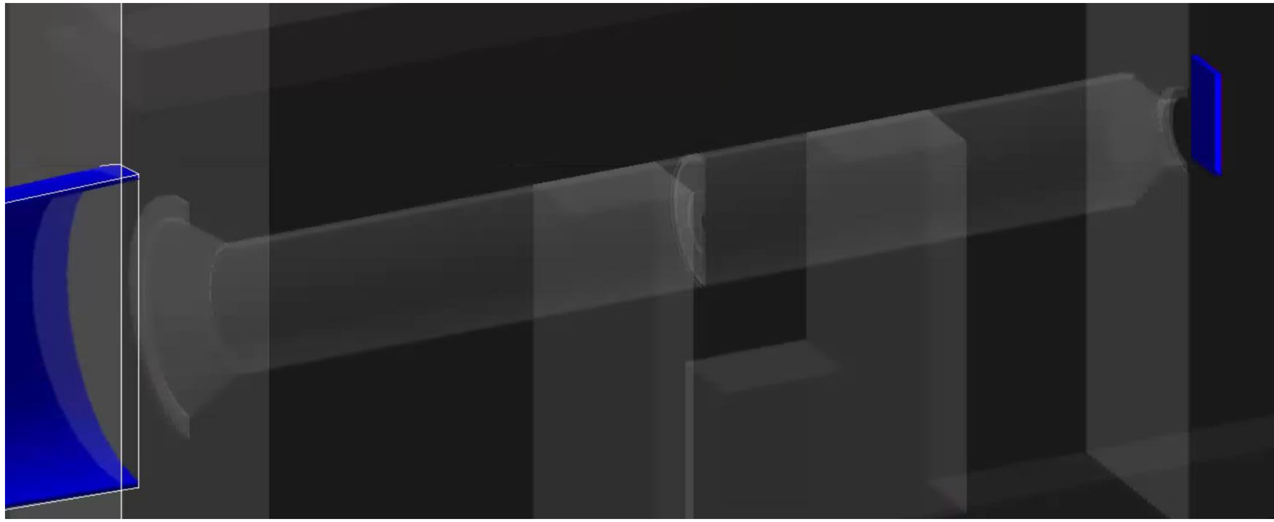


CAD layout of MD

Current geometry

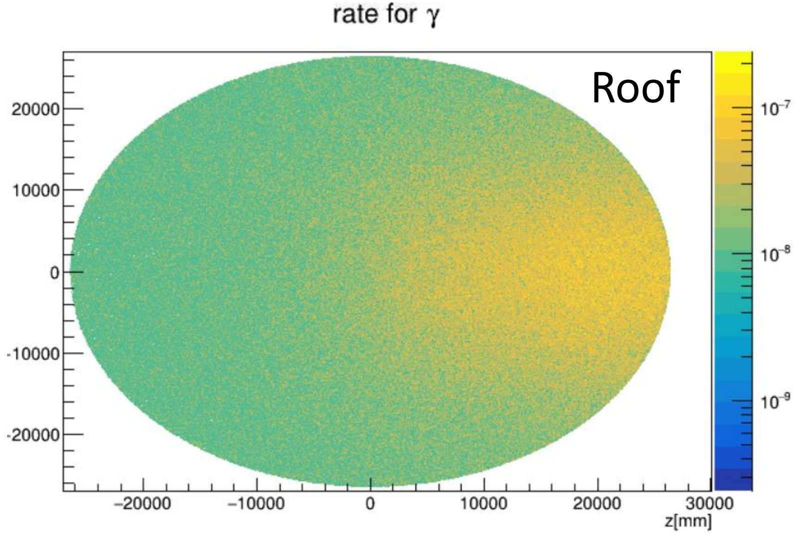
- Sensitive area in the location of the Main Detector PMTs and Retracted GEMs used for estimates
- Drift pipe, collars, detector pipe as well as shower max and pion Pb doughnut included
- Dump tunnel, beampipe (with correct neckdowns), aperture plate, diffuser and water tank included
    - We didn't see any hits coming back from the water tank so in the future we will stop the beam downstream of the diffuser
- Simulation ran with beam generator with a fringe magnetic field down to **R=2mm**

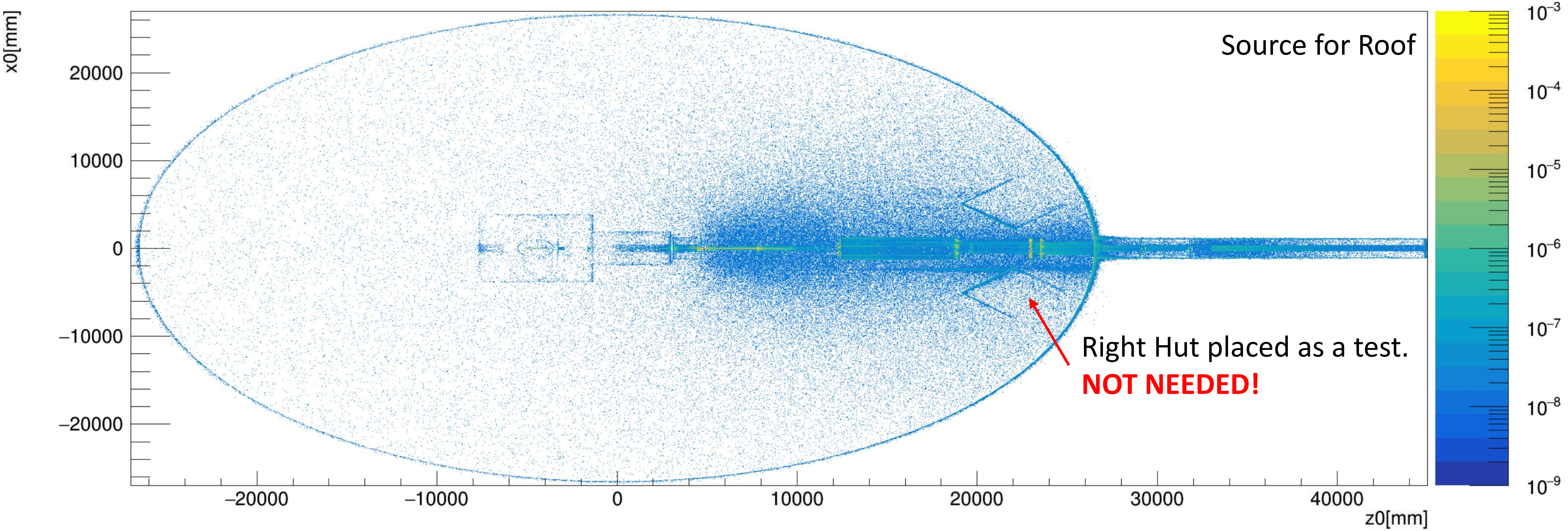




Hall detectors

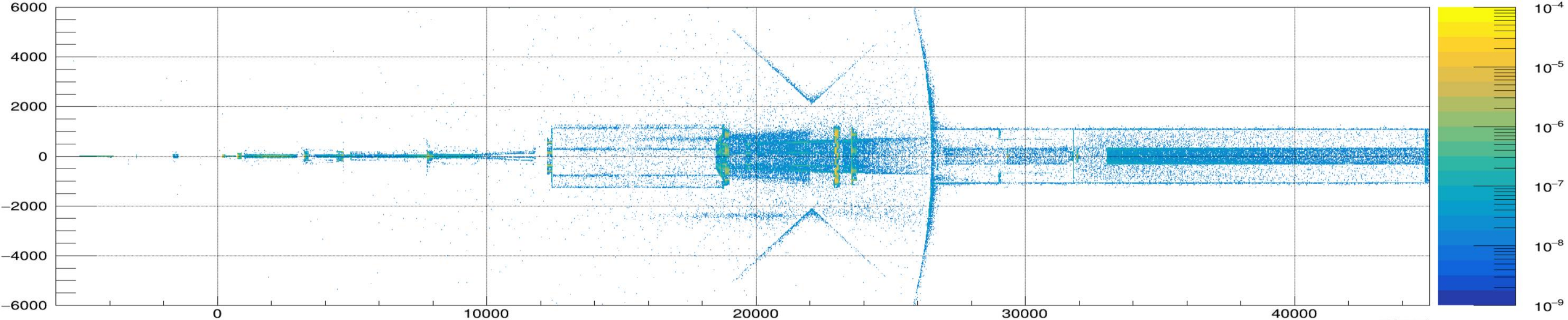
- The particle density on the roof is peaked close to the wall (we will need to include part of the wall in our boundary estimate)
- We can see that although we put more than 5kW of power in the target and collimator 1 each they don't shine as much as the downstream elements

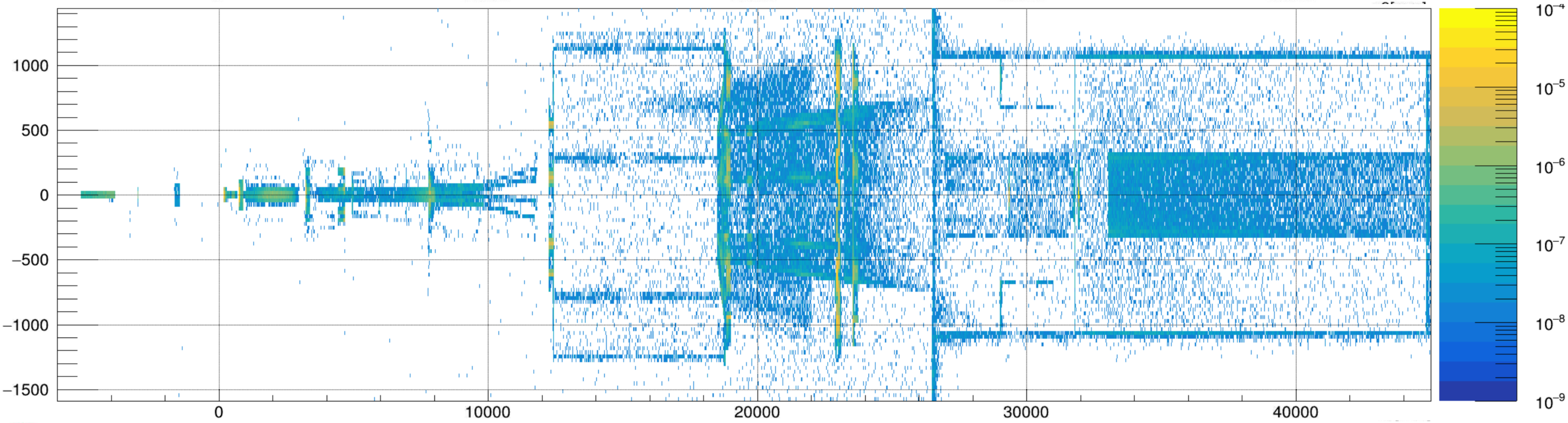




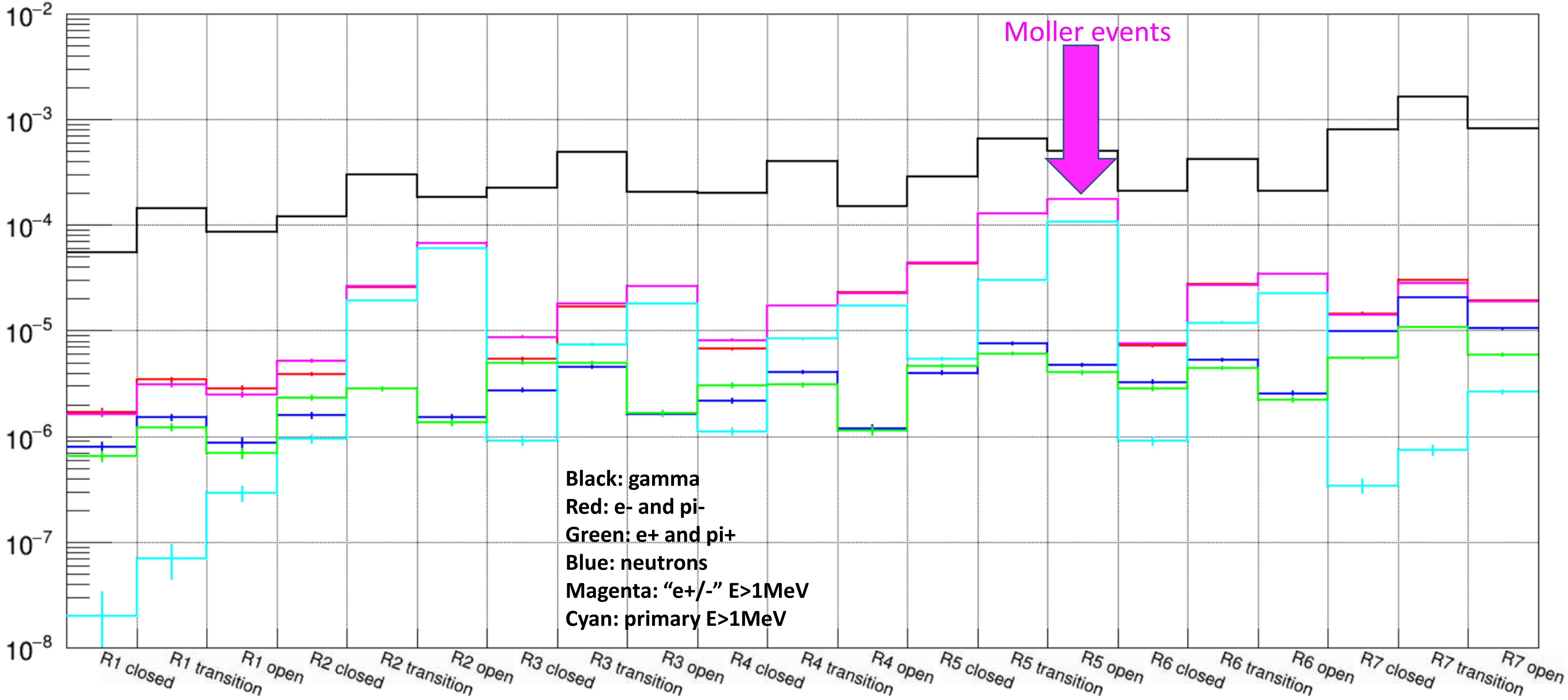
Right Hut placed as a test.
NOT NEEDED!

Main detector sources (Rings 1 through 7)





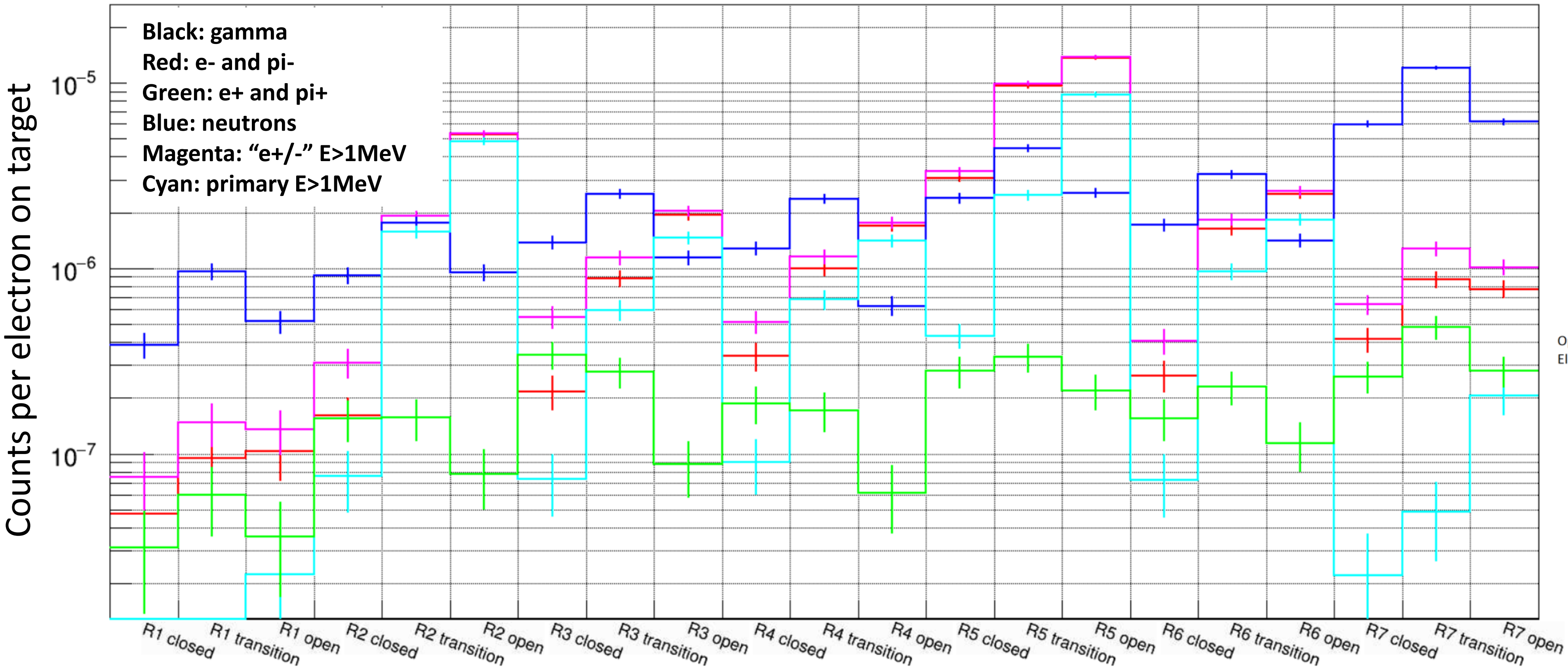
Main detector rates

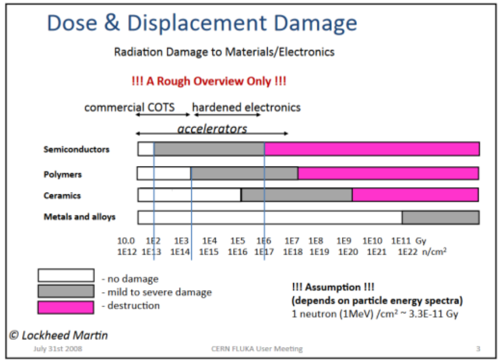


Moller events

Black: gamma
Red: e- and pi-
Green: e+ and pi+
Blue: neutrons
Magenta: “e+/-” E>1MeV
Cyan: primary E>1MeV

Normalization of NIEL numbers




Dose & Displacement Damage

Radiation Damage to Materials/Electronics

!!! A Rough Overview Only !!!

!!! Assumption !!!
(depends on particle energy spectra)
1 neutron (1MeV) /cm² ~ 3.3E-11 Gy

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Commercial off-the-shelf (COTS) electronics are typically robust up to neutron doses of about $10^{13}\, n/\, cm^2$.

Optocouplers are significantly softer, with failure at 1E11 *1-MeV* n_{eq}/cm^2
Electronics are also subject to prompt failure (e.g. single event upset)

- Scale NIEL numbers in ring 7 by: 1.6e17 (full PAC days)
- We can clearly see that we are dominated by neutrons and we reach about 1E12 1-MeV n_{eq}/cm^2 without any shielding (Chandan has more details about this) for the entire life of the experiment
- Closest sensitive electronics to this location will be the PMT bases which will be radially out from Ring 7 and have some local shielding

Project Recommendation: 2016 Dec DR.03.R-04/R-10

R-04: Splashback from the Shower Max Detector should be simulated to see the impact on the Thin Detector ring signals.
R-10: Complete the shielding studies around the beam dump to ensure there is no excessive noise in the main MOLLER detectors.

R1-6 e- Rate	tgt	tgtReg	coll1&2	USmag	coll3&Pb	usDSmag	coll5	dsDSmag	collar1	driftPipe	collar2	airUSMD	SM & Donut	end of DetPipe	dump Neck Down to Apperture	dump Apperture	Apperture to NeckDown2	neckDown & Diffuser	ds of Diffuser
all E %	63%	0%	0%	0%	0%	0%	0%	0%	2%	1%	5%	14%	15%	0%	0%	0%	0%	0%	0%
E<1MeV[%]	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	2%	47%	57%	0%	0%	0%	0%	0%	0%
1<E<10MeV%	0%	0%	0%	0%	1%	0%	0%	0%	3%	3%	11%	34%	47%	0%	0%	0%	0%	0%	0%
10MeV<E%	88%	0%	0%	0%	0%	0%	0%	0%	2%	0%	4%	3%	0%	0%	0%	0%	0%	0%	0%

- We can estimate the impact of the different regions on the detector signal by looking at the rate of electrons reaching the Main Detector quartz area (particularly with energy larger than 1MeV)
  - Detailed numbers can be found in docDB577 (for MD and PMT regions separated by species)
- The target account for about 80% of electrons reaching the MD, the air in front of the detector accounts about the same amount as the SM (8%)
- We can see that we don’t get any significant amount of electrons from DS of the SM

Project Recommendation: 2016 Dec DR.03.R-10b

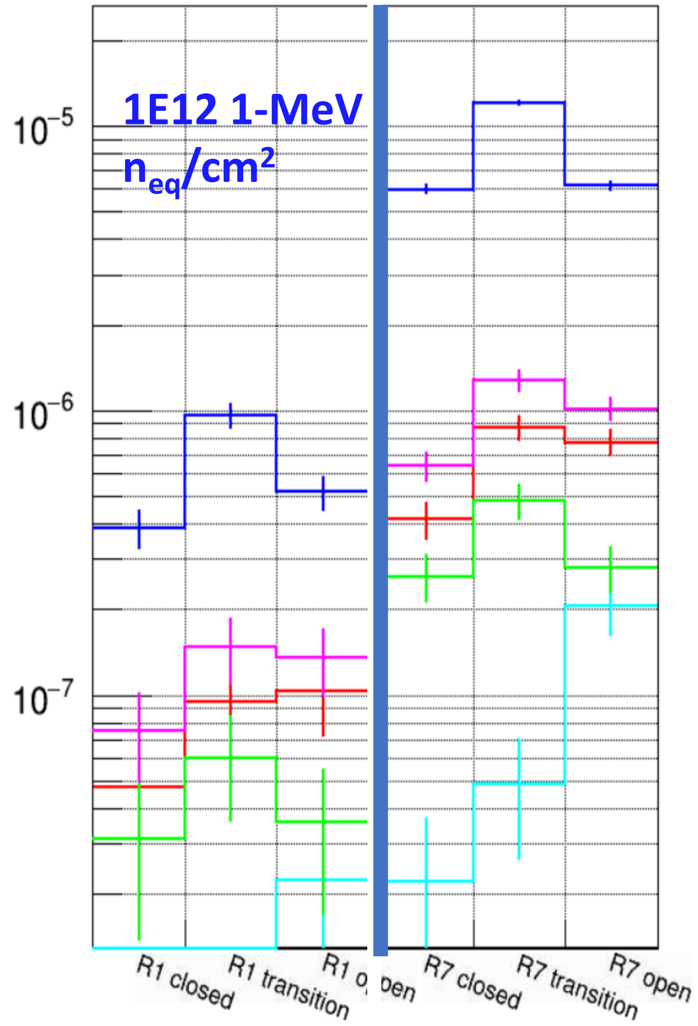
Complete the shielding studies around the beam dump to ensure there is no excessive noise in the main MOLLER electronics.

R7 n Rate*NIEL	tgt	tgtReg	coll1&2	USmag	coll3&Pb	usDSmag	coll5	dsDSmag	collar1	driftPipe	collar2	airUSMD	SM & Donut	end of DetPipe	dump Neck Down to Apperture	dump Apperture	Apperture to NeckDown2	neckDown & Diffuser	ds of Diffuser
all E %	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	5%	1%	67%	1%	2%	1%	3%	14%	4%
E<1MeV[%]	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	6%	0%	79%	0%	3%	1%	3%	5%	2%
1<E<10MeV%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	5%	1%	65%	1%	1%	1%	3%	16%	5%
10MeV<E%	0%	0%	0%	0%	0%	0%	0%	1%	2%	1%	3%	1%	27%	3%	3%	0%	4%	46%	8%

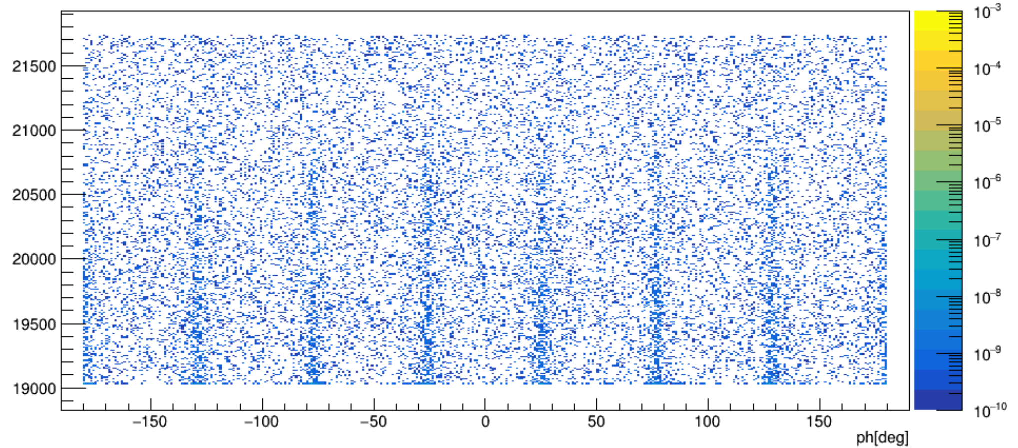
- With respect to noise in electronics closest to the beamline we can look at the NIEL "dose" in Ring 7 separated by the same regions
- We can see that while the diffuser dominates the high energy neutron damage the dump overall is not a big issue compared to the SM and Pion doughnut (factor of 5 smaller)
- We conclude that the dump will not require significant changes or shielding to allow for uninterrupted experimental running

Project Recommendation: 2019 Apr DR.05.R-09

Prepare a plan to handle possible radiation damage to the front end electronics, pending the results of the radiation field estimates.



- Estimations inside the electronics hut - **8E10 1-MeV n_{eq}/cm^2** - and at the location of the retracted GEMs - **4E12 1-MeV n_{eq}/cm^2** - (see Chandan’s talk) show that we are significantly lower than levels where permanent damage will be an issue
    - The GEM numbers are highly position dependent and we envision locating the most sensitive components in the closed sectors so that we avoid unnecessary exposure



Other recommendations: thoughts

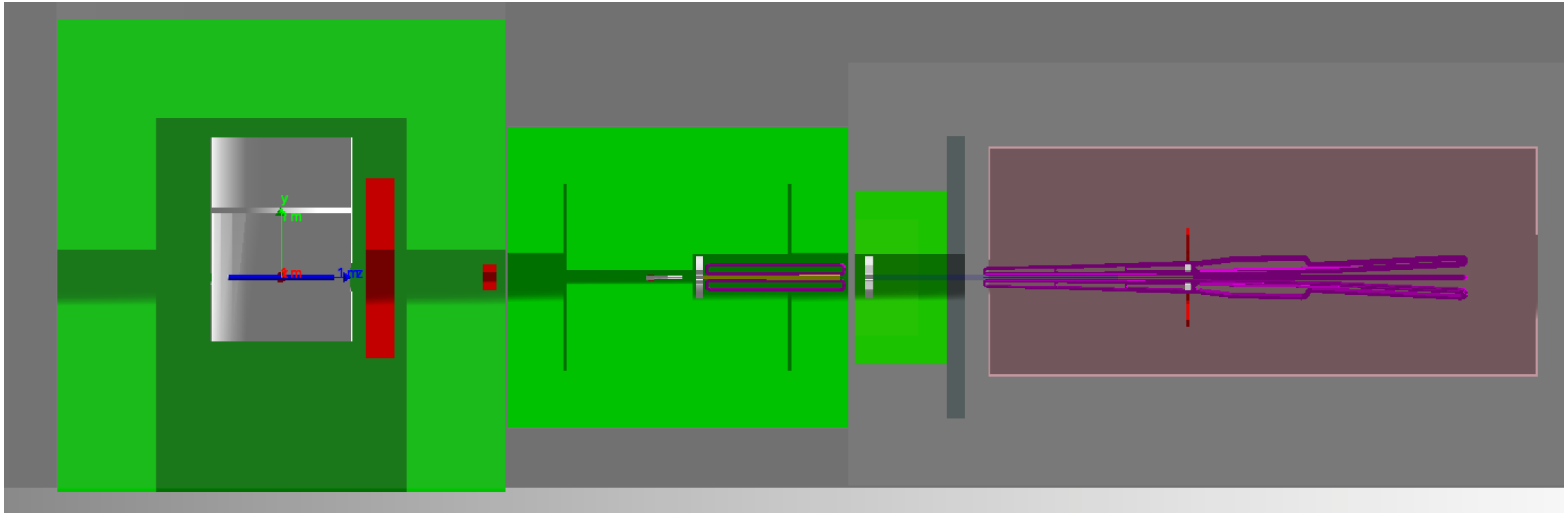
2016 Dec DR.03.R-05	Cross-talk between detector regions due to showering in the support structure of the Thin Detector should be simulated.		Work is progressing and we expect to get results by the end of the summer
2019 Apr DR.04.R-08	Complete the inclusion of the detailed detector geometry into the detector simulation to confirm design choices, and verify that the final design meets the requirements of the experiment.		We will continue integration of the different components as design progresses (including the detector supports and frames).
2016 Dec DR.03.R-09	Simulations of the combined apparatus and hall are needed, for example, to assess backscattering backgrounds from the dump in the pion detectors.		At this point it should be fairly straightforward to add sensitive detectors at the location of the Pion detectors and PMTs and perform a similar analysis as for the other areas.

Some thoughts on next steps

- Geometry updates:
    - Electronics hut requirements can be relaxed (open the top and increase the walls, reduce the thickness of the walls); placement will be revisited once design progresses
    - **S**mall **A**ngle **M**onitor region (SAMs with tubes and quartz as well as Pb doughnut) needs to be included in the simulation and optimized to not increase radiation field
    - Dump tunnel geometry needs to be updated to include the effect of the dirt overbearing
    - Optimization of the target and collimator 1 region will need to go in parallel with design of the area to catch problems as they appear
    - Collar 1&2 optimizations will improve the radiation field at the GEMs and the MD PMTs
    - Collimator 1 and 2 merging and possible redesign for improved heat dissipation
- Analysis scheme to evaluate Single Event Upsets occurrence should be developed
- Improve analysis of the boundary dose in coordination with RadCon
- Evaluate efficiency of the Dump Ion Chambers for machine protection (in particular seeing the radiation field produced by the diffuser)
- Re-run analysis with full fringe field

Backup

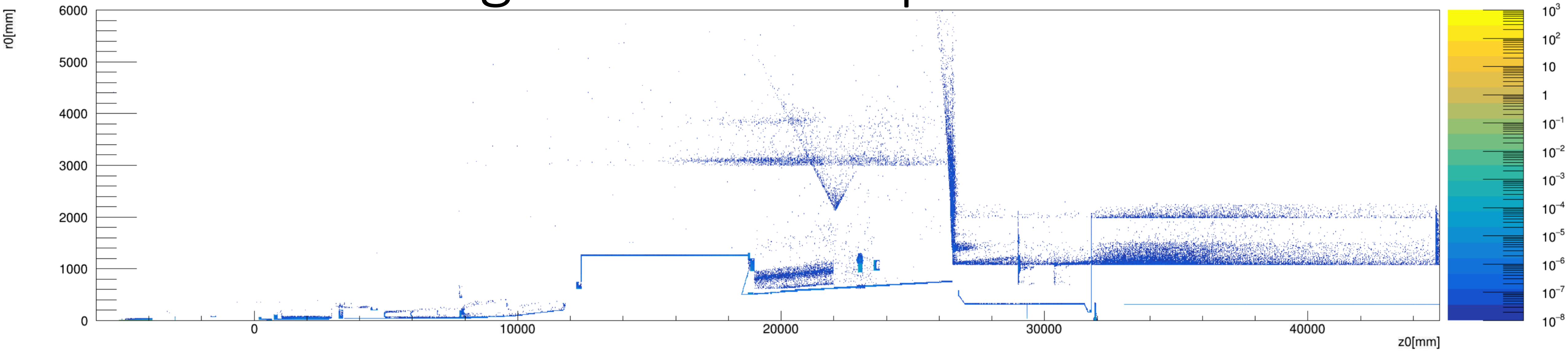
Radiation issues inside the hall: Mitigation strategy

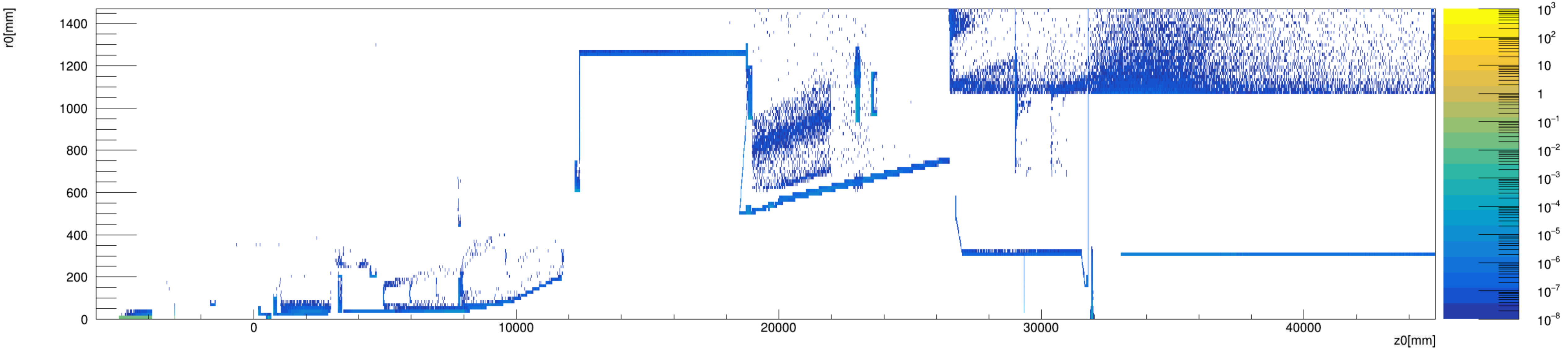


- We focused our efforts on reducing radiation as close as possible to the source (locations with high power depositions)
  - The target and collimator 1&2 regions are the most important
- We investigated the effect of slit scattering and reduced amount of background reaching the detector plane

collimator	**Power @65uA, 1.25m Tgt**
1	6700 W
2	2000 W
4	126
5+Lintel	22

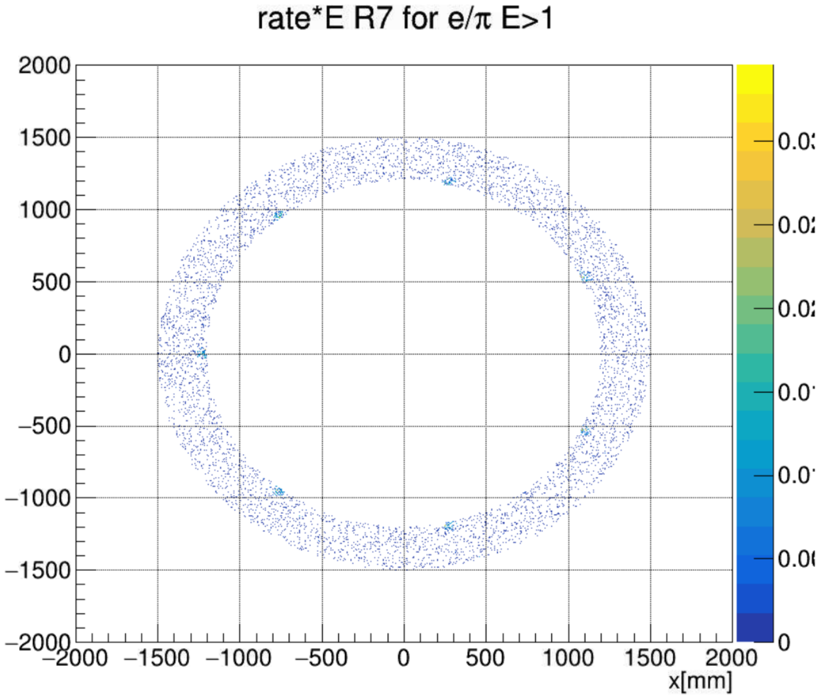
Photons reaching **full** detector plane: GeoV2

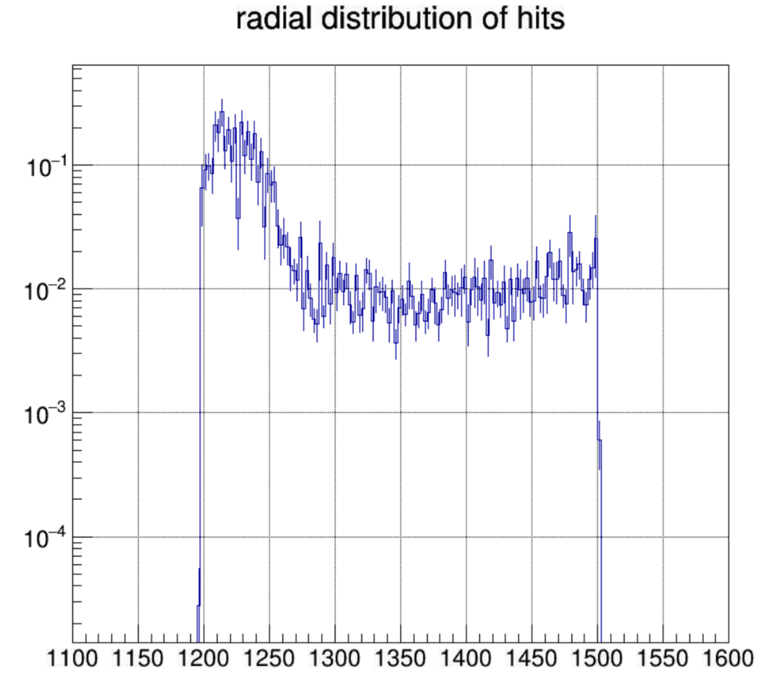


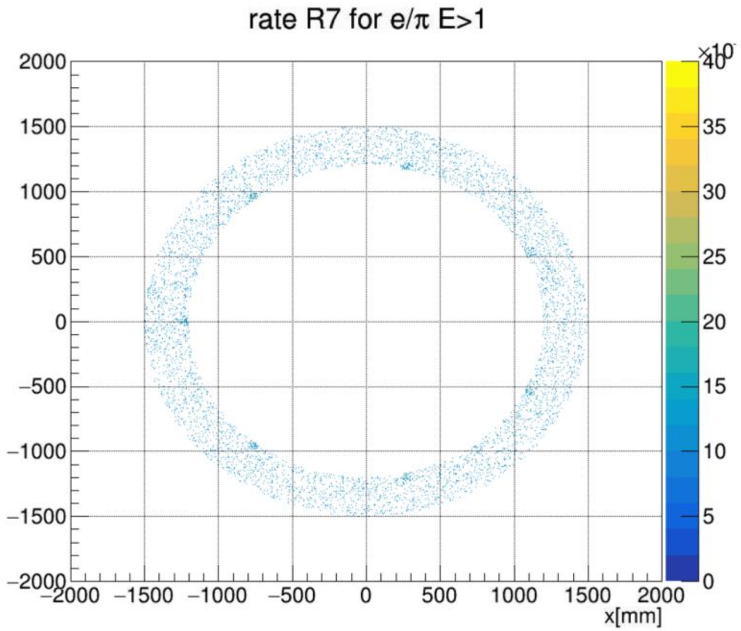


PMT ring : GeoV2

- We can see that Collar2 seems to allow high energy particles up to a radius of ~1270mm skewing the PMT numbers
    - Reason why the rate*E numbers on previous plots see such a large number from the target


rate*E R7 for e/π E>1


radial distribution of hits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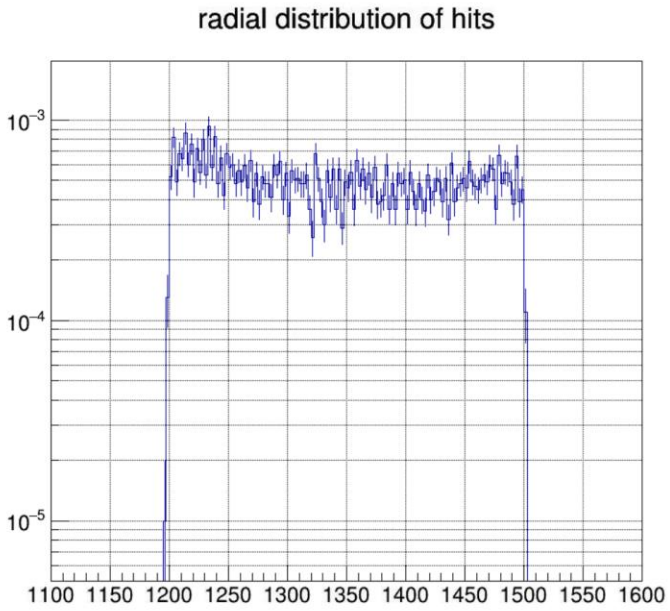
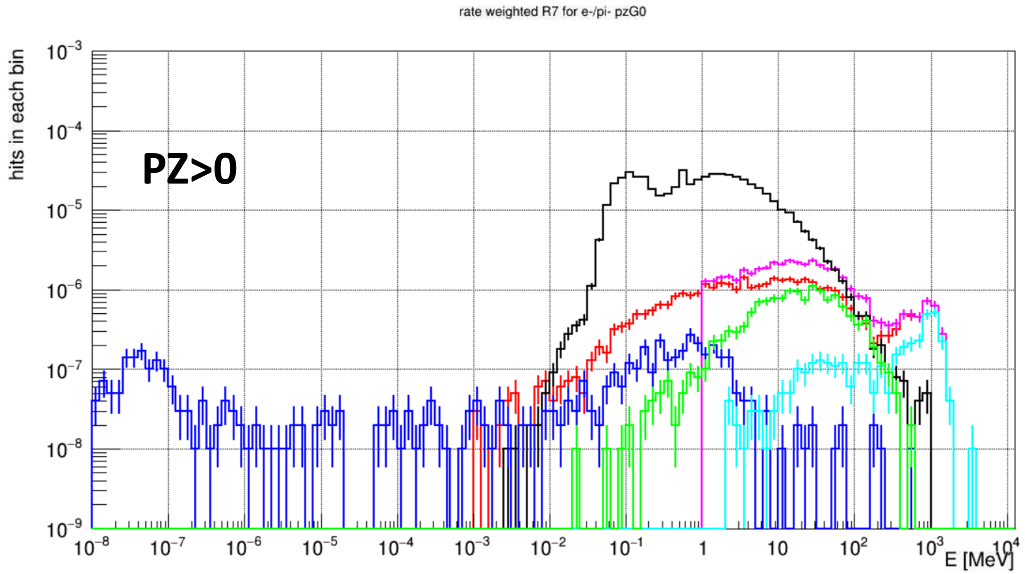
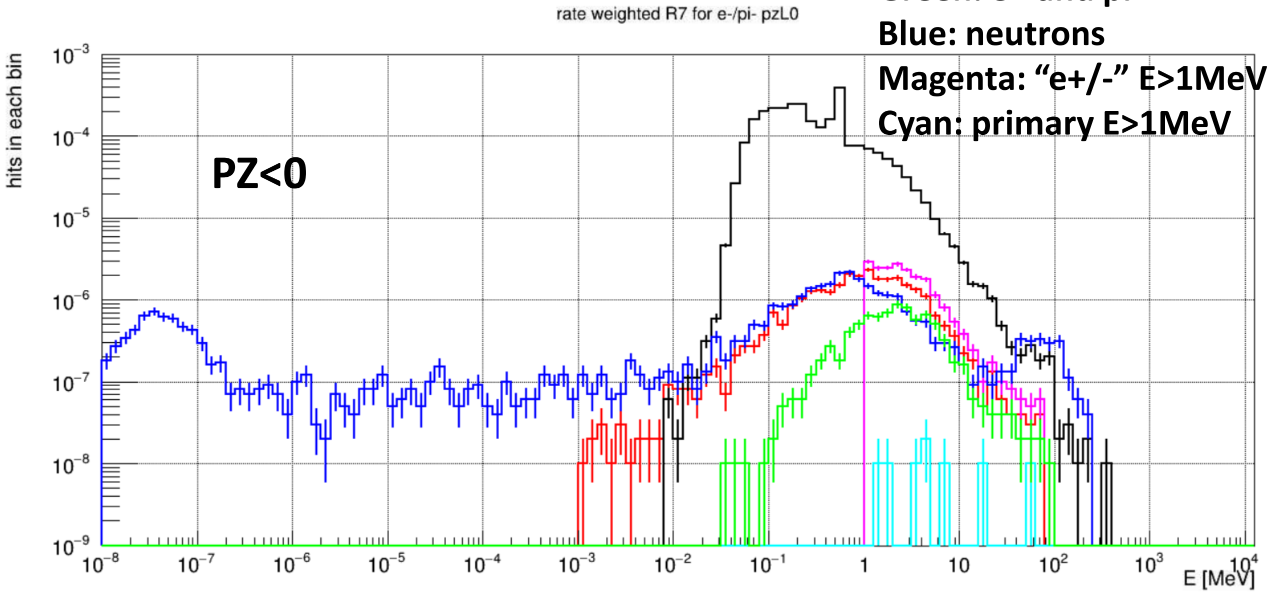
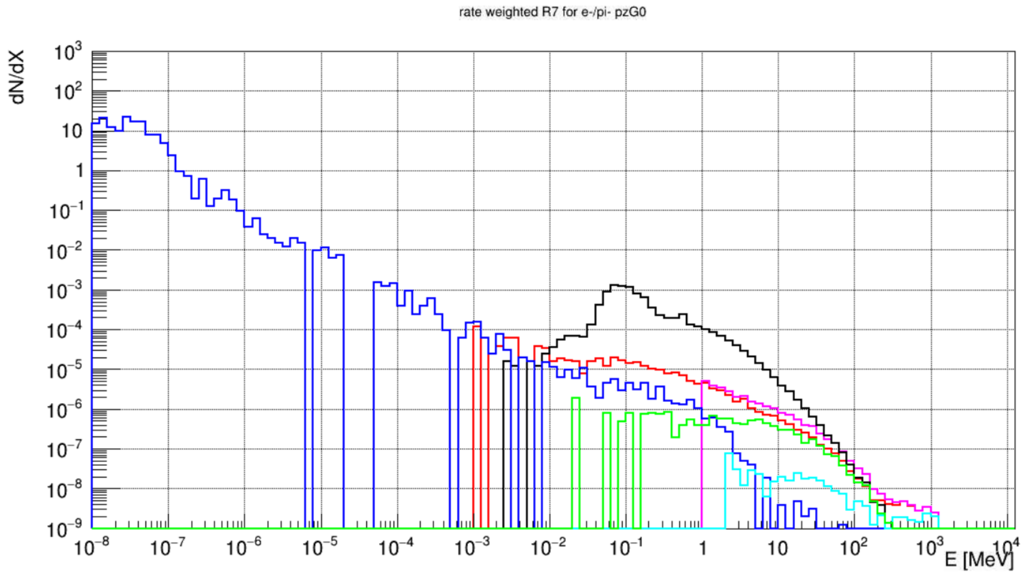

radial distribution of hits

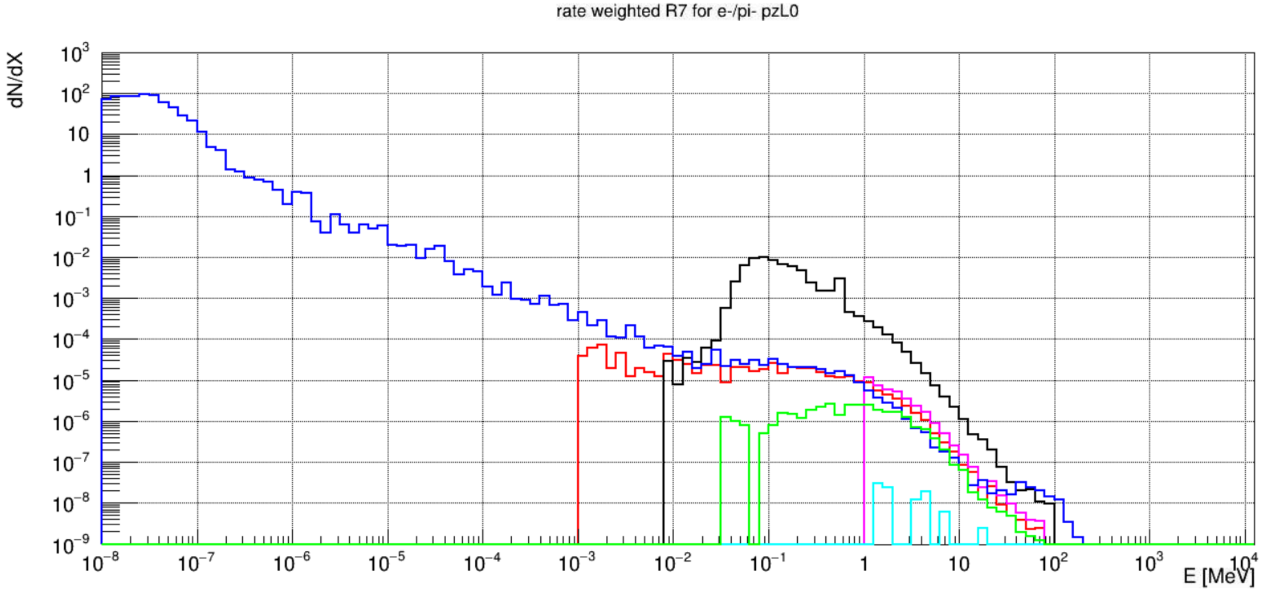
R7 kinE distributions : GeoV2

Black: gamma
Red: e- and pi-
Green: e+ and pi+
Blue: neutrons
Magenta: “e+/-” E>1MeV
Cyan: primary E>1MeV









R7 NIEL distributions : GeoV2

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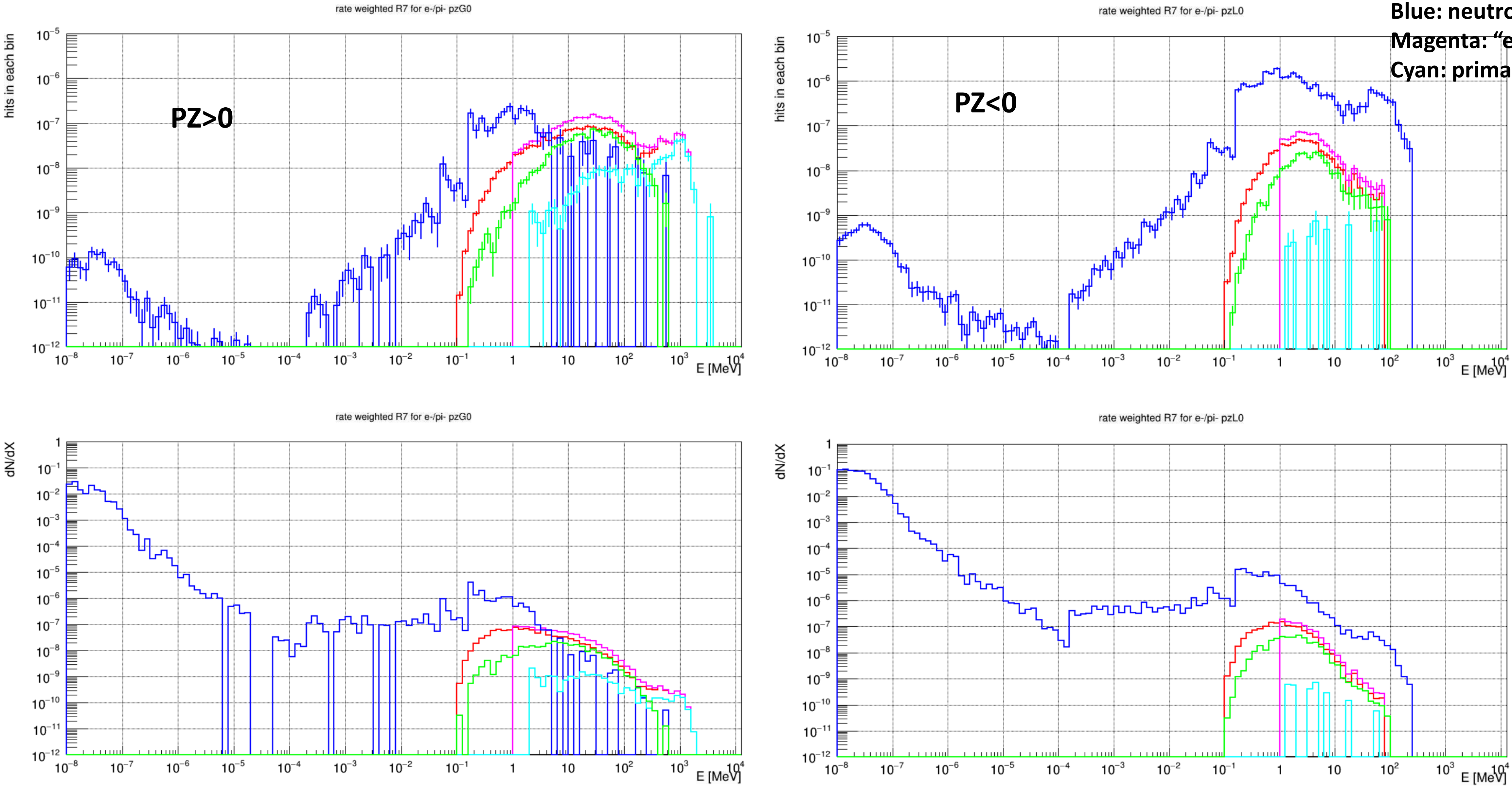
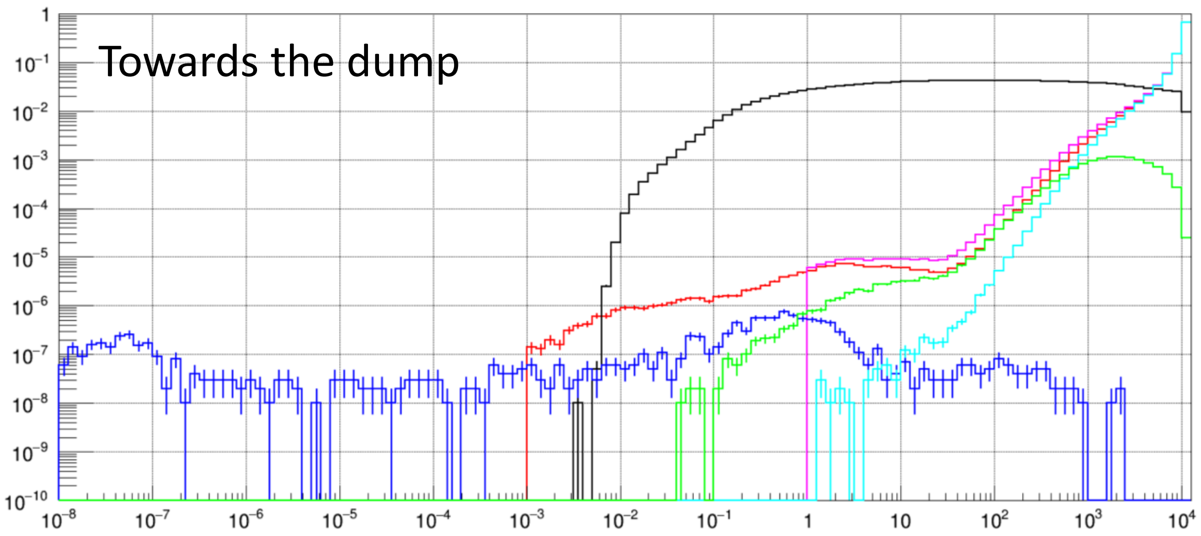
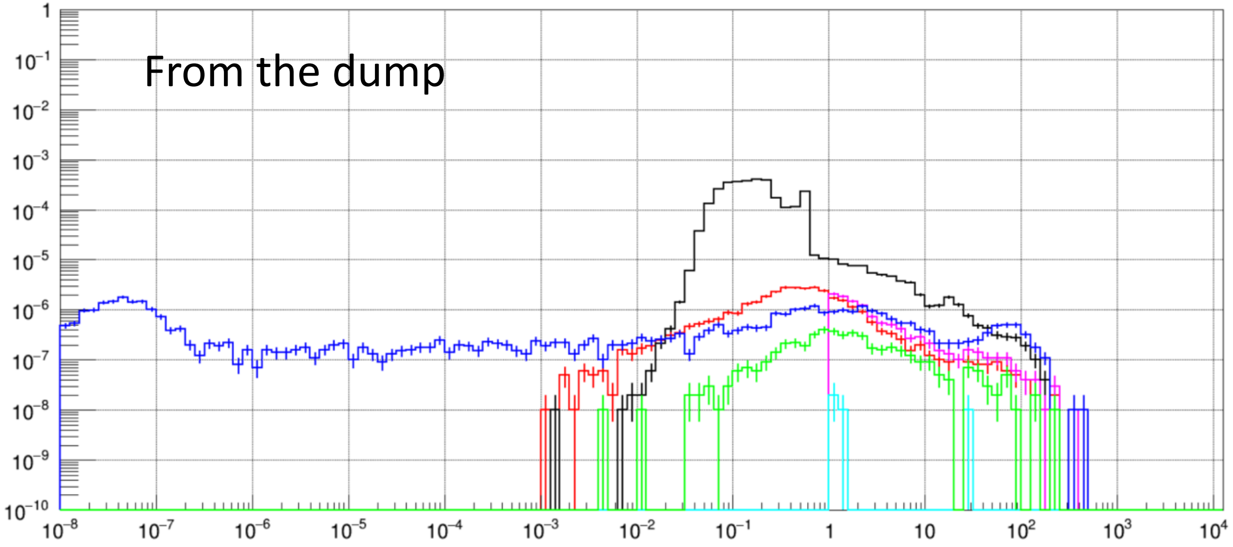
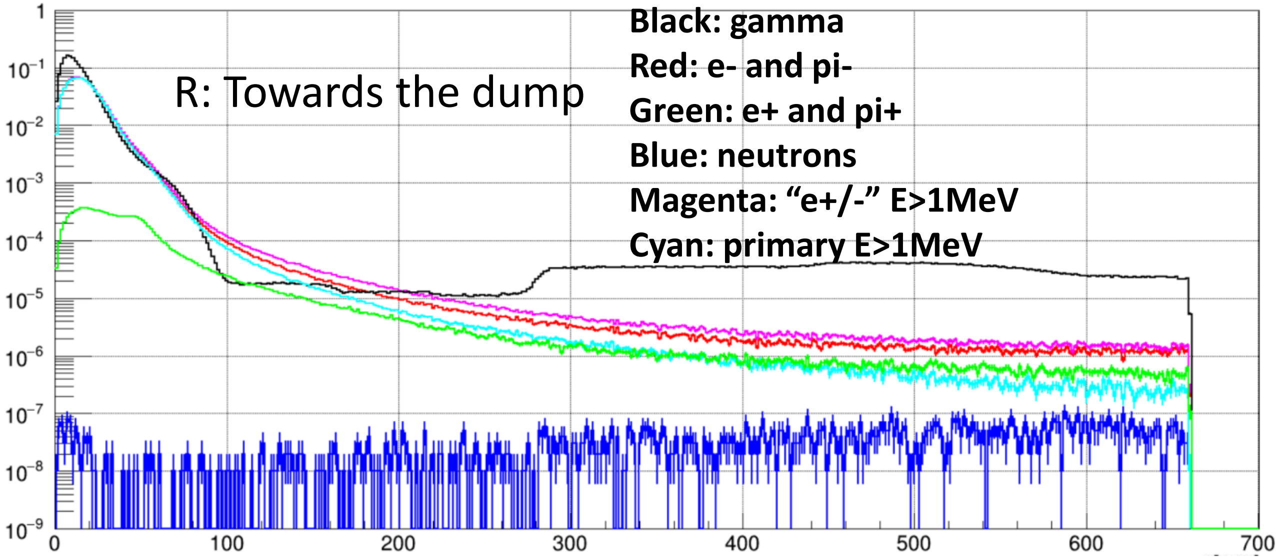
Cyan: primary E>1MeV



Beamline detectors: SAMs


Towards the dump


From the dump


R: Towards the dump

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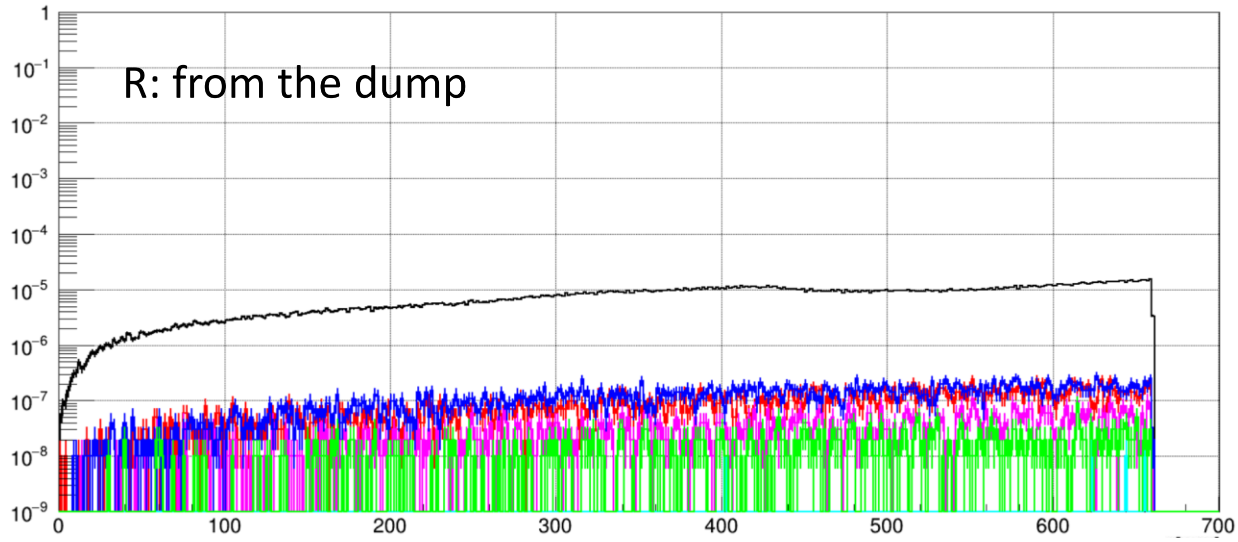
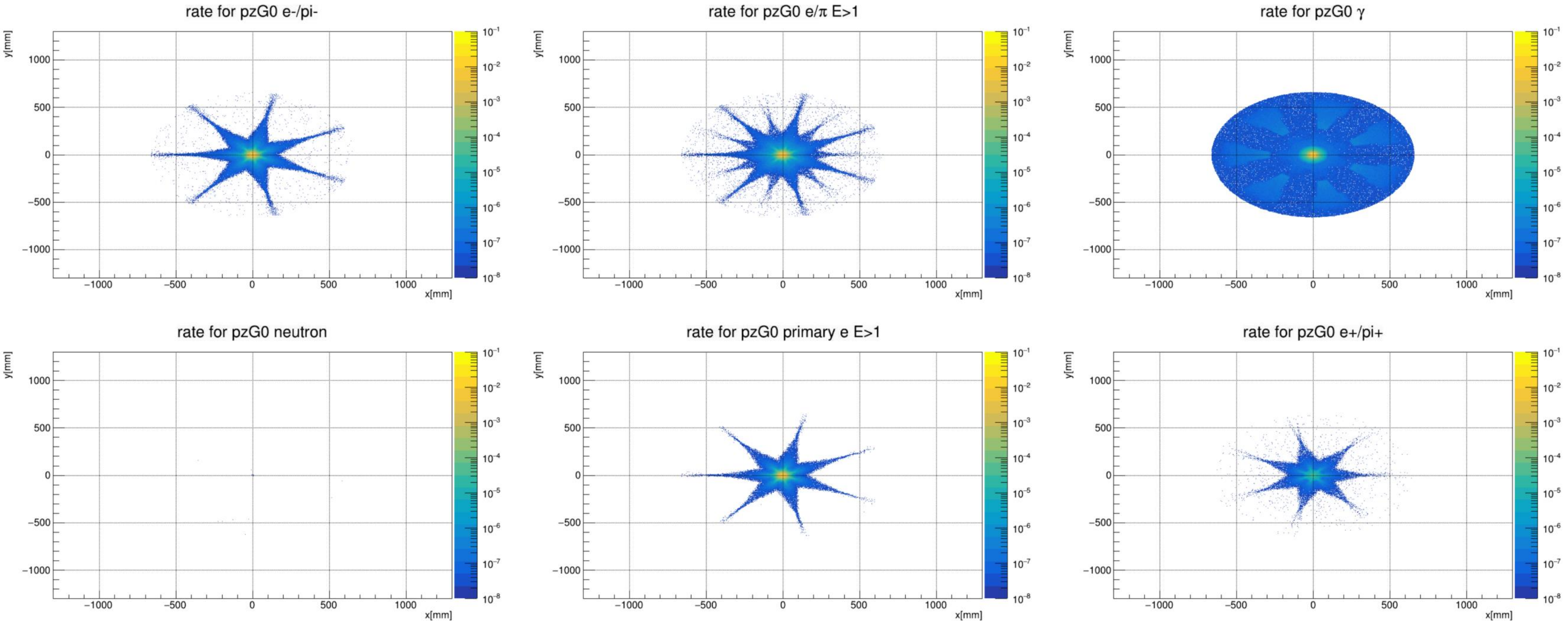
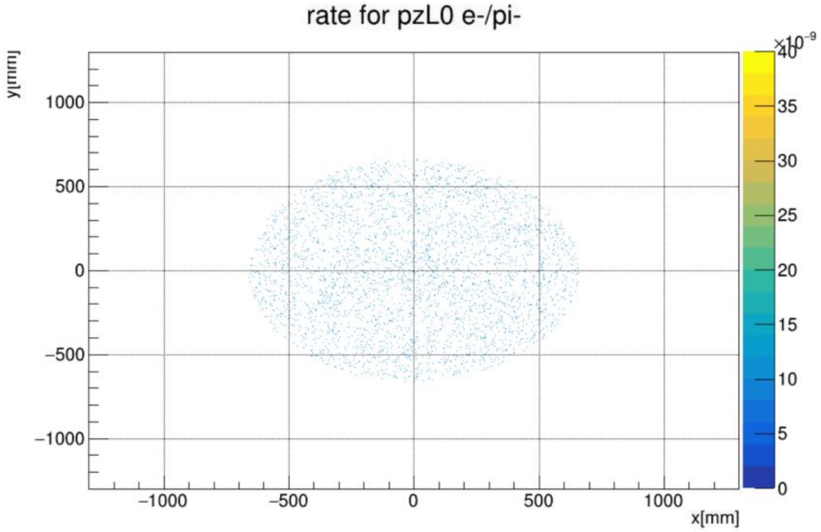
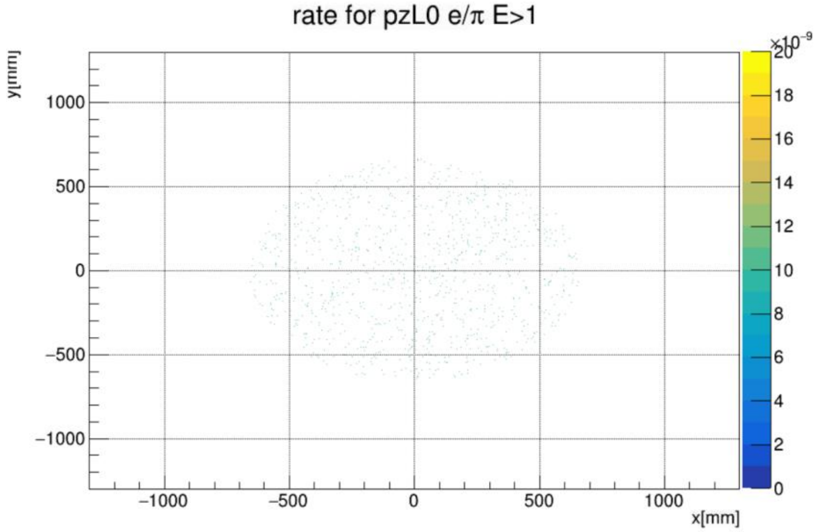

R: from the dump

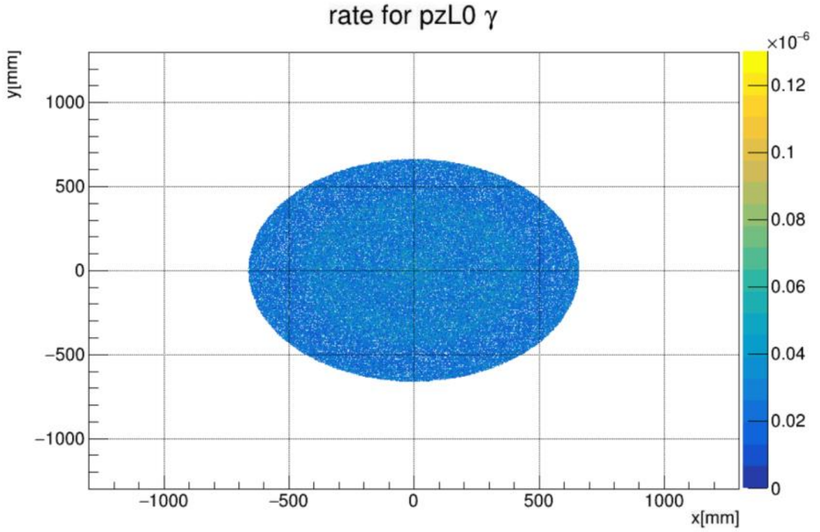
Beamline detectors: SAMs (rate towards the dump)

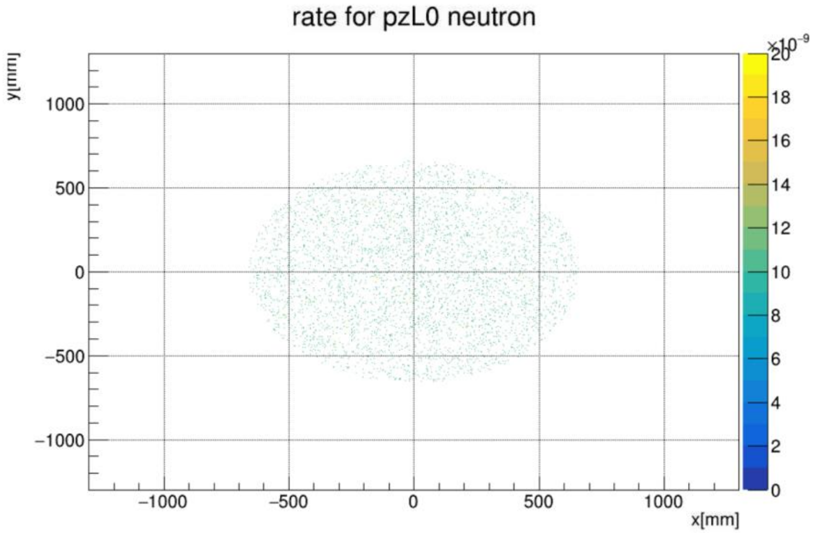


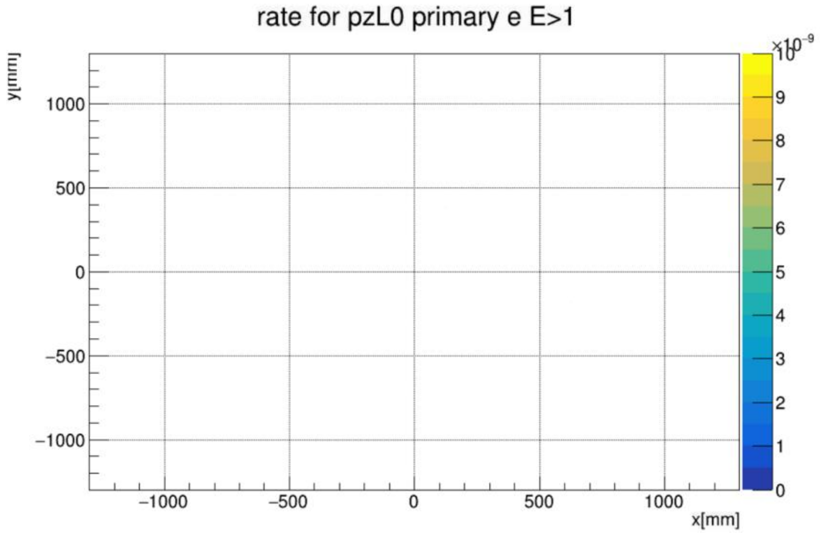
Beamline detectors: SAMs (rate from the dump)

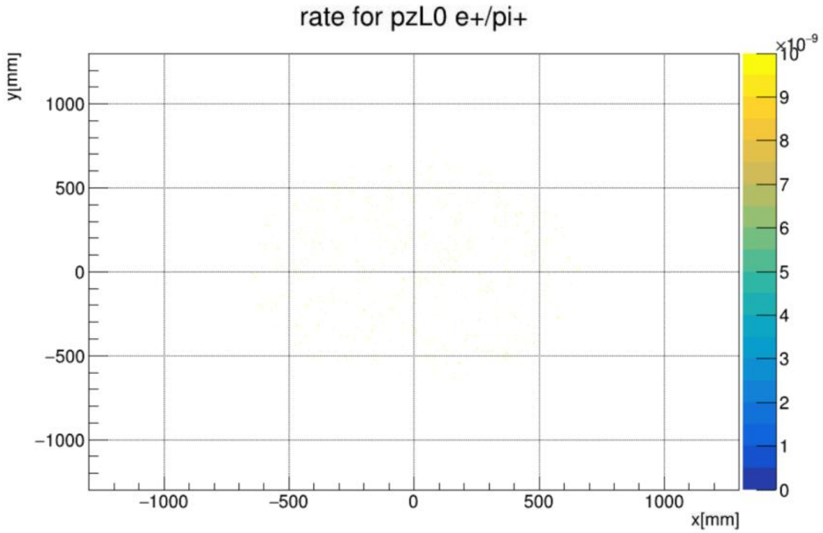




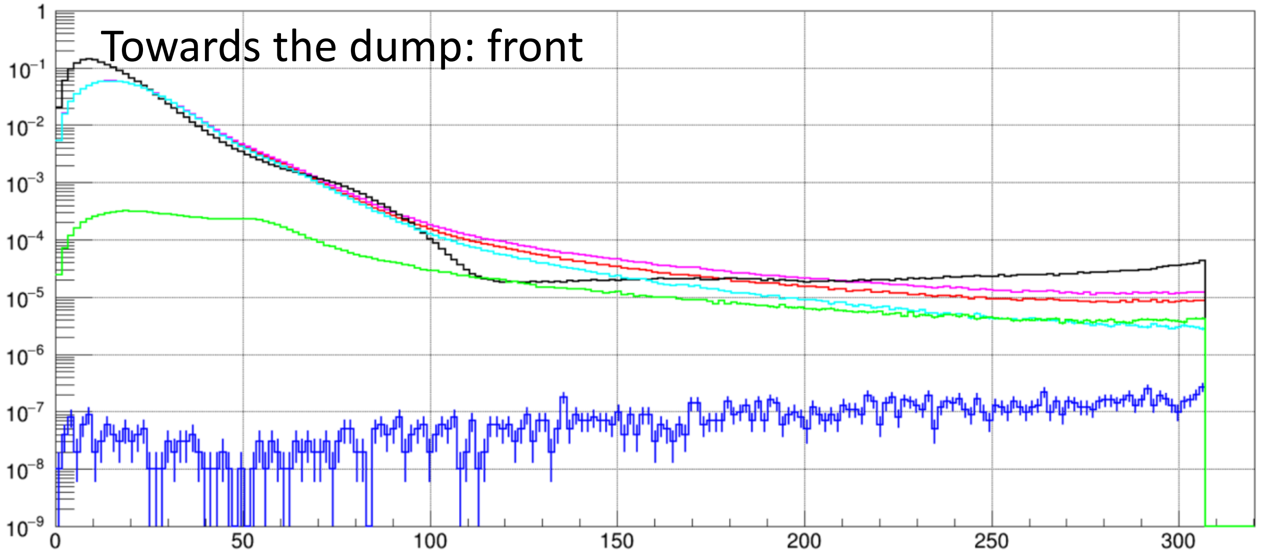


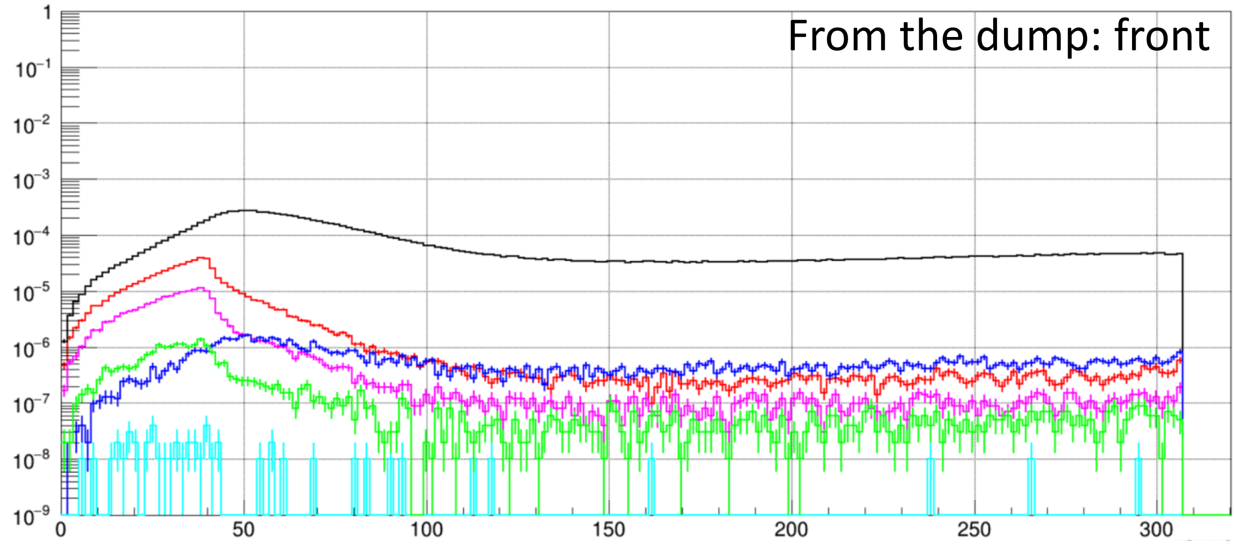


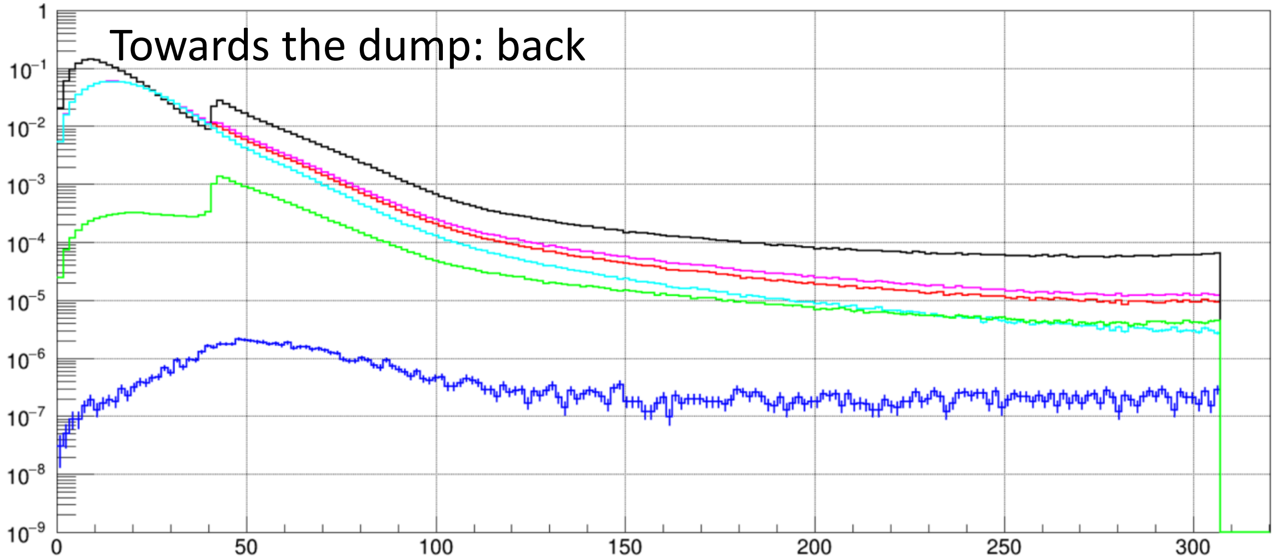


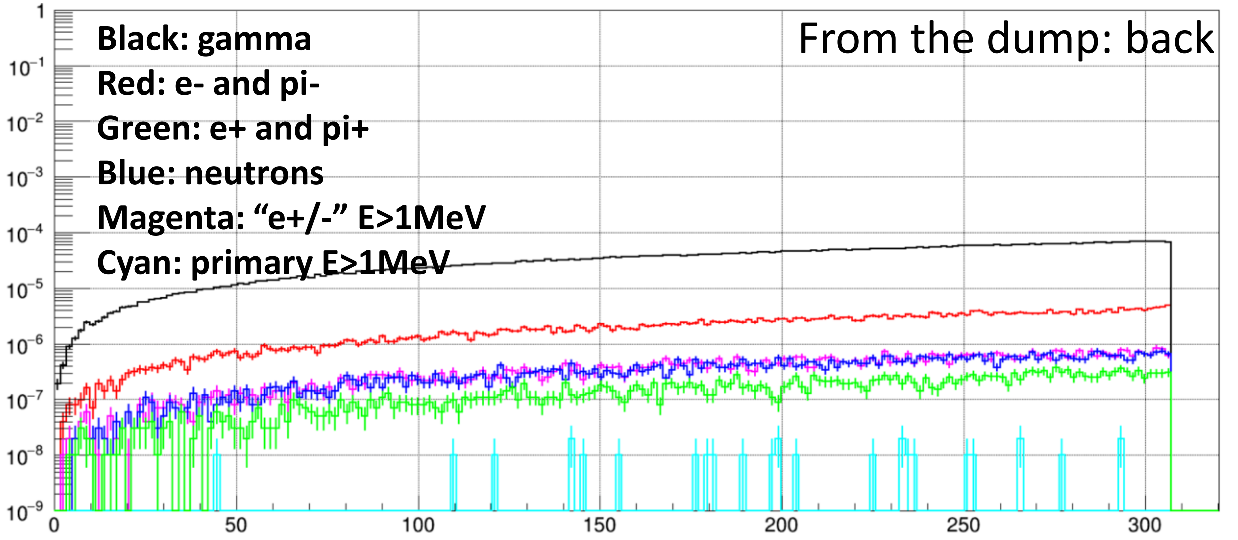


Beamline detectors: back dump donut

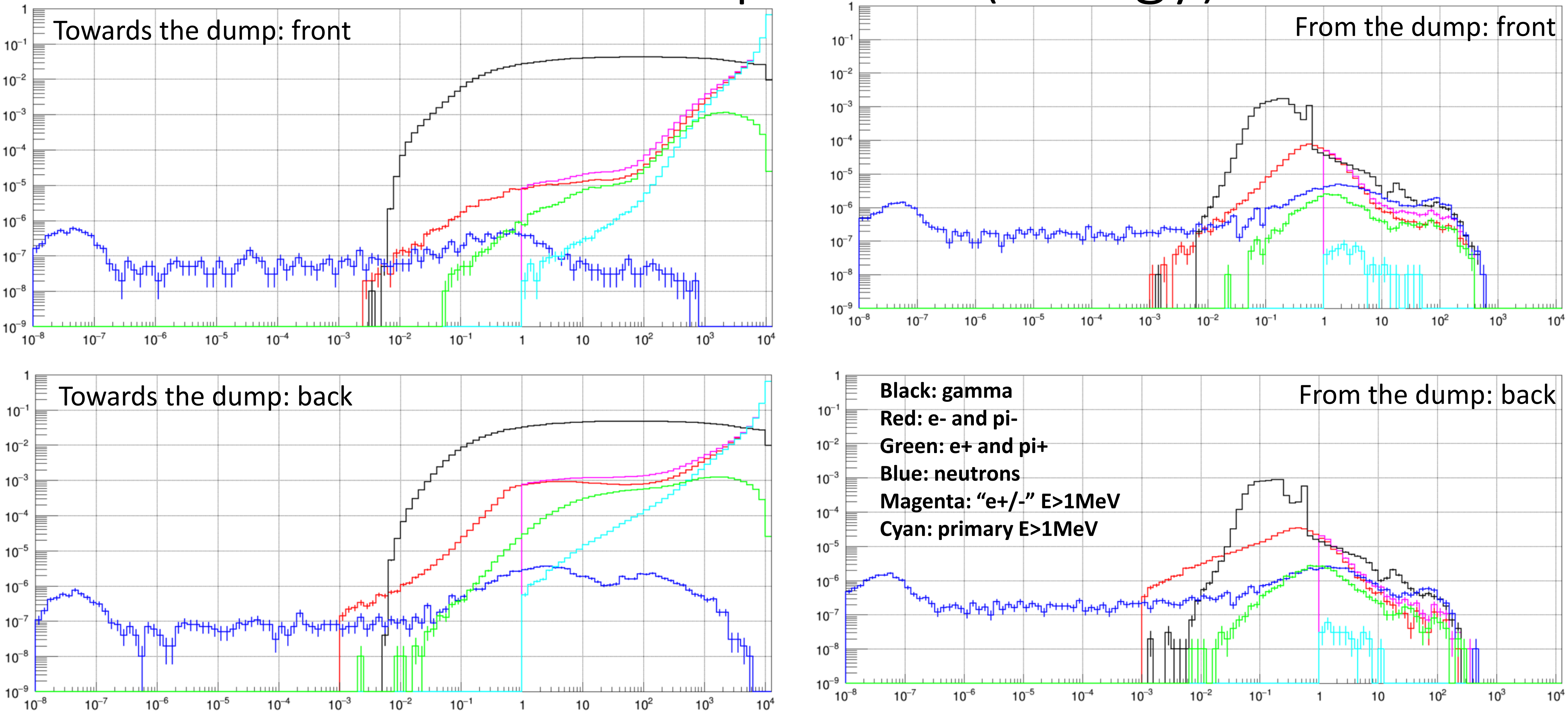

Towards the dump: front


From the dump: front

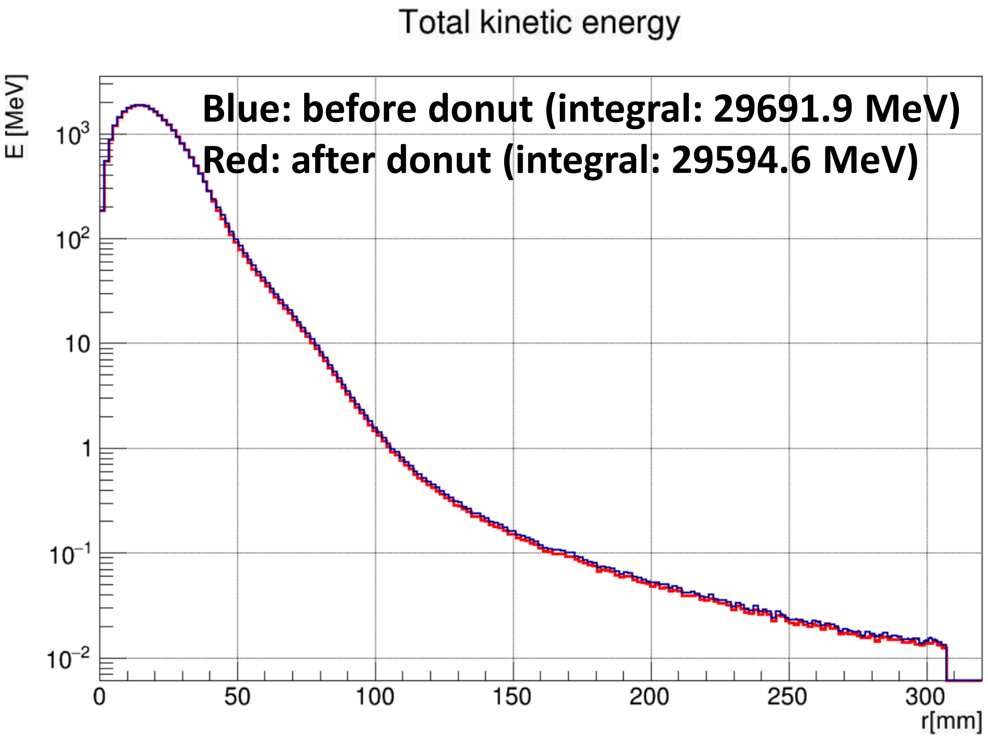

Towards the dump: back


From the dump: back

Beamline detectors: dump donut (energy)



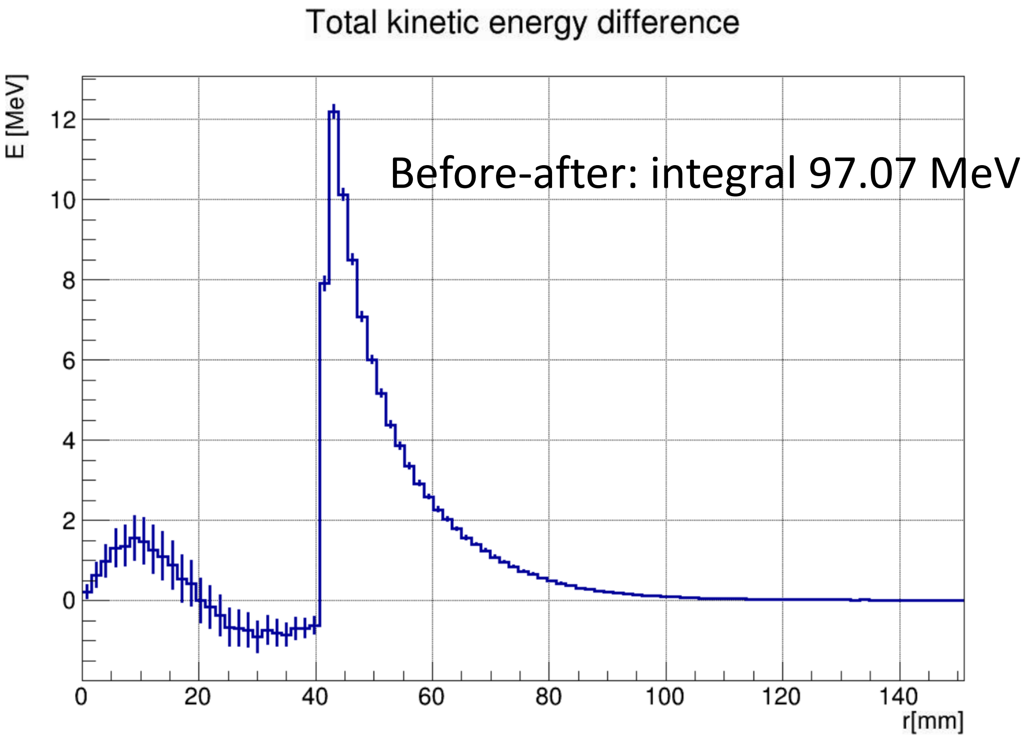
Dump donut energy deposition



Total kinetic energy

Blue: before donut (integral: 29691.9 MeV)

Red: after donut (integral: 29594.6 MeV)



Total kinetic energy difference

Before-after: integral 97.07 MeV

- Scaling the energy deposited in the donut by the current (in uA) we get the energy deposition in W: 6.309kW