The Status of Beam Dumps for PERLE

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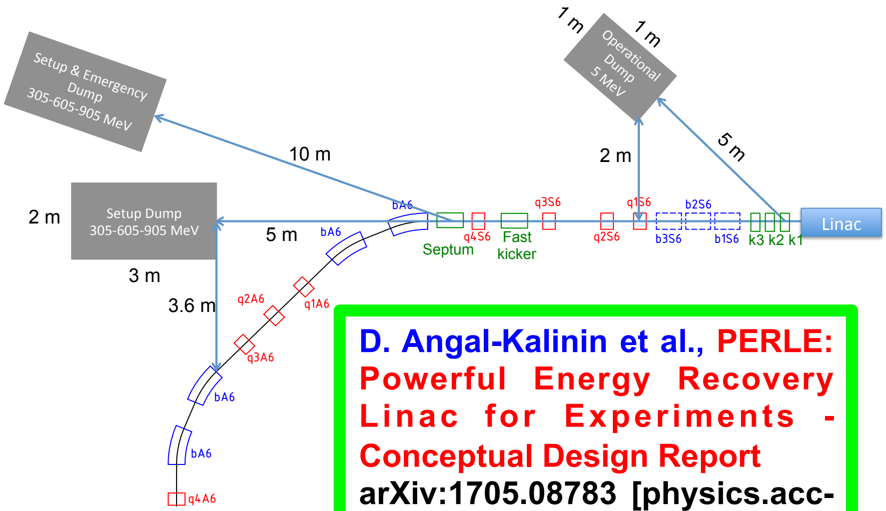
Outline

- Introduction
- Design Considerations
- Operational Beam Dump
- Simulation Results
- Summary

PERLE Beam Dumps (BD)

The transfer lines to the operational, setup and setup&emergency beam dumps



D. Angal-Kalinin et al., PERLE: Powerful Energy Recovery Linac for Experiments - Conceptual Design Report arXiv:1705.08783 [physics.acc-ph] 2017

1. Operational BD:

The nominal operation of PERLE foresees to continuously dump the decelerated 5 MeV electron beam; this corresponds, for a current of 12.8 mA (now 20mA), to a constant power deposition of 64 kW (now 100kW) on the beam dump.

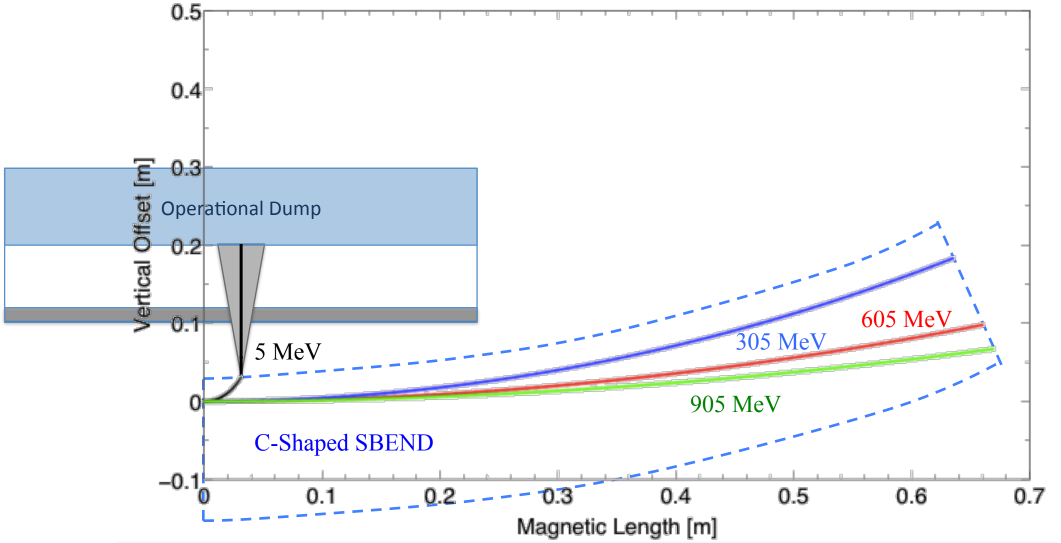
2. Setup BD

During the commissioning period of PERLE, and in general during the beam setup, it is important to be able to dump the beam at the different energies.

3. Setup&Emergency BD was proposed to quickly switch the beam out in case of a problem in the machine.

Some rationalization of the number of dumps and their functionality should still be made.

Operational Beam Dump



Due to the strong edge effects and the low energy, the beam size increases rapidly.

Thin layer (with hole) of a heavy material should be installed at the entrance of the dump for reducing the backscattering towards the recirculating beam.

No additional magnet has to be installed in the main lattice. A 0.66 m long dipole (SBEND) with a 0.906 T magnetic field acts as a spectrometer and separates vertically the different energy beams to direct them towards the respective superimposed arc. This magnet can be used to deflect the 5 MeV beam towards a vertical beam dump. The 5 MeV beam gets a deflection of about 90° in 3 cm and is extracted from the magnetic field region.

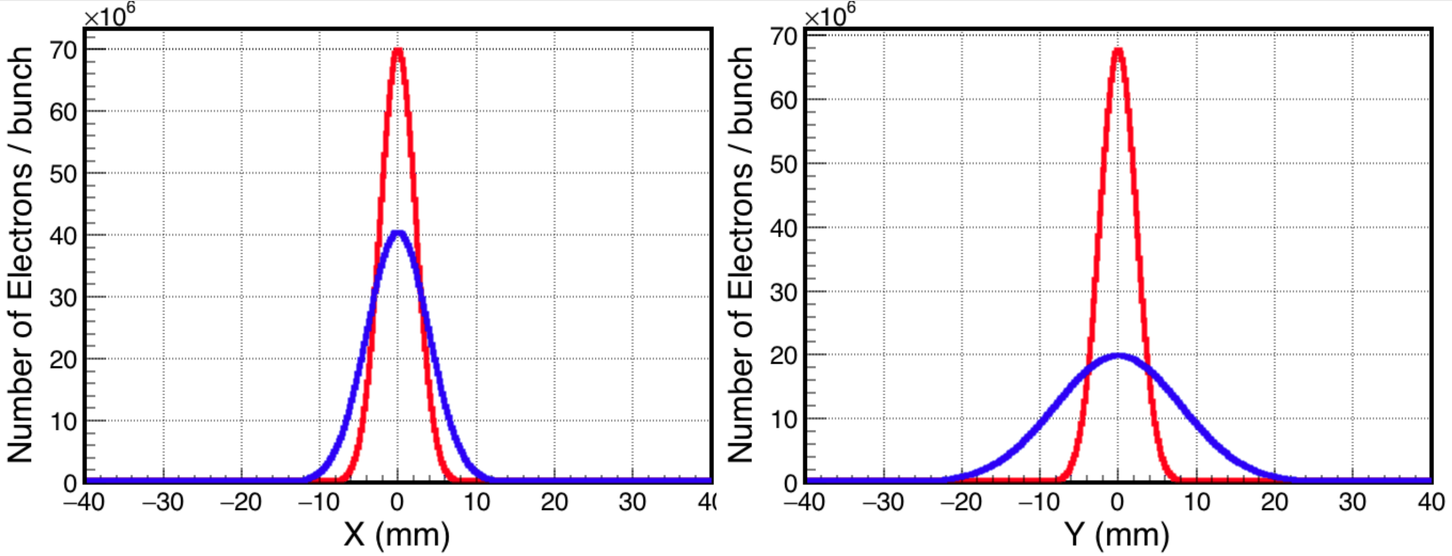
Electron Beam Parameters used in Simulations

The considered dump made by one block of a single material of graphite. Iron made absorber is considered as well. A cylinder with 20 cm radius and a length of 10 cm was chosen for the absorber and placed 5 m from the bending magnet.

Beam Energy	MeV	5.0
Bunch Popul.	10^9	3.1
Bunches/Beam/sec		$4*10^7$
σ_x	mm	2.28134
$\sigma_{x'}$	mrad	0.64523
σ_y	mm	2.35349
$\sigma_{y'}$	mrad	1.53629
σ_p / P		0.001

Energy (MeV)	Current (mA)	Electrons/ bunch/10^7
5	12.8	200
155	0.41	6.5
305	0.21	3.3
455	0.14	2.2
605	0.11	1.7
755	0.08	1.3
905	0.07	1.1

Beam Spatial Distribution after Bending Magnet and on the Surface of BD (Gaussian fit)



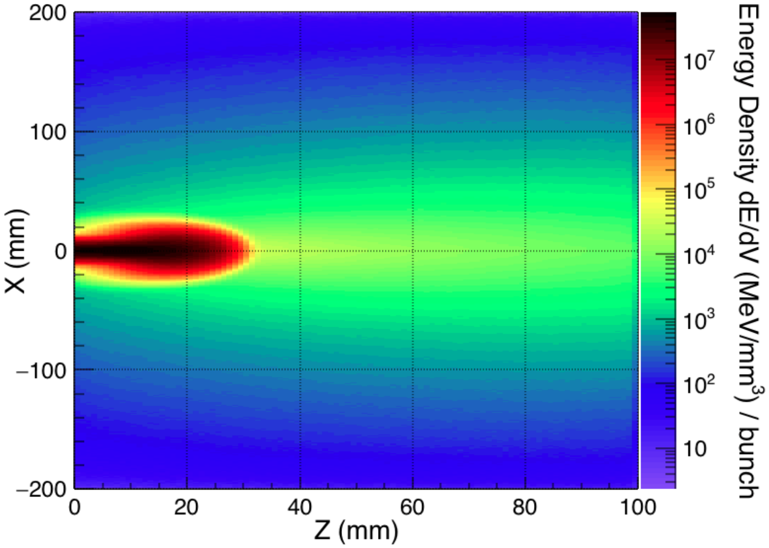
Red line – after bending magnet

Blue line – on the surface of BD

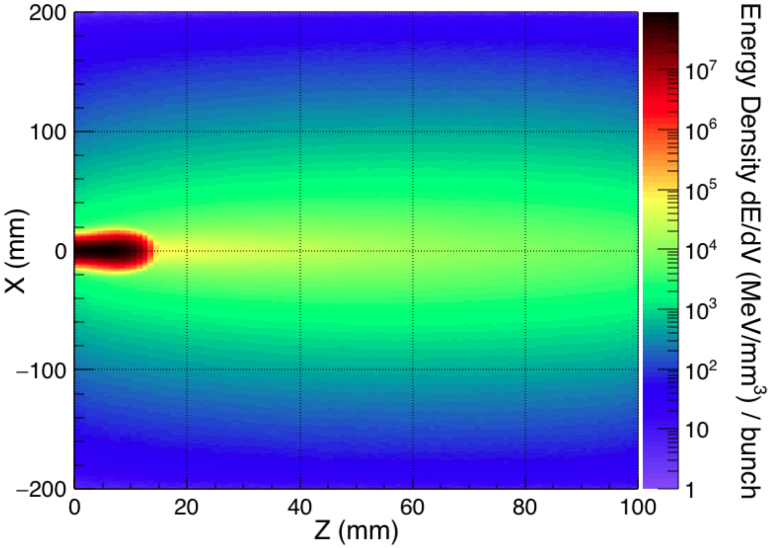
		After Bend.	On BD
σ_x	mm	2.28	3.95
σ_y	mm	2.35	8.03
Beam size	mm^2	5.36	31.72

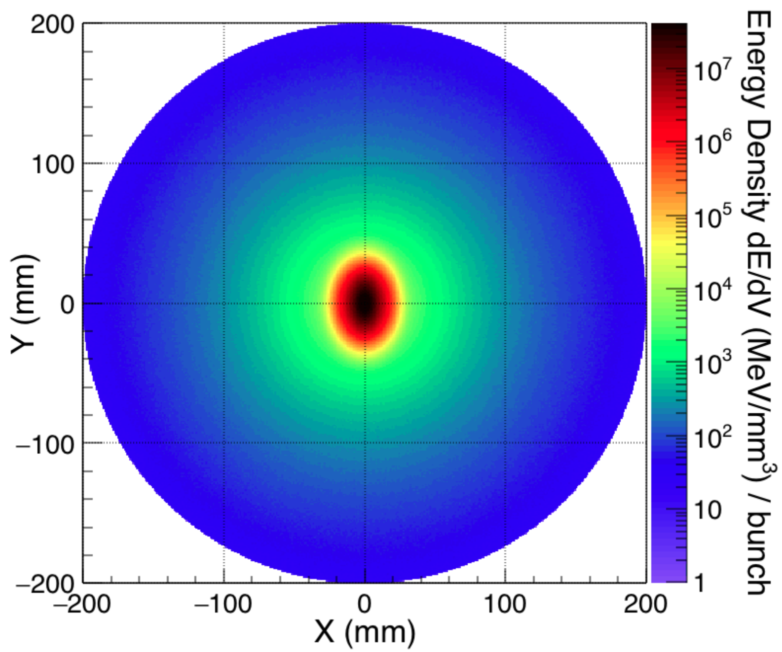
Deposited Energy Density in the Graphite

1.0 g/cm^3



2.27 g/cm^3





Deposited energy density contours for the graphite absorber with different densities. Main energy deposition is concentrated within a narrow cylinder around the beam trajectory with σ_x= 5.94 mm and σ_y= 9.35 mm .

Temperature Rise (ΔT) in the Beam Dump

The maximum energy deposition density by one bunch of electrons ($3.1*10^9$, 5MeV) in the graphite is found to be $4.23*10^{-7}$ J/mm^3, which is equivalent to $4.23*10^{-4}$ J/g. The associated peak temperature rise in the unit volume of graphite due to the impact of one bunch of electrons is $\Delta T = 5.88*10^{-4}$ °C.

If we assume 25ns bunch spacing then ΔT is ~23,000 °C per second, assuming no thermal diffusion or cooling.

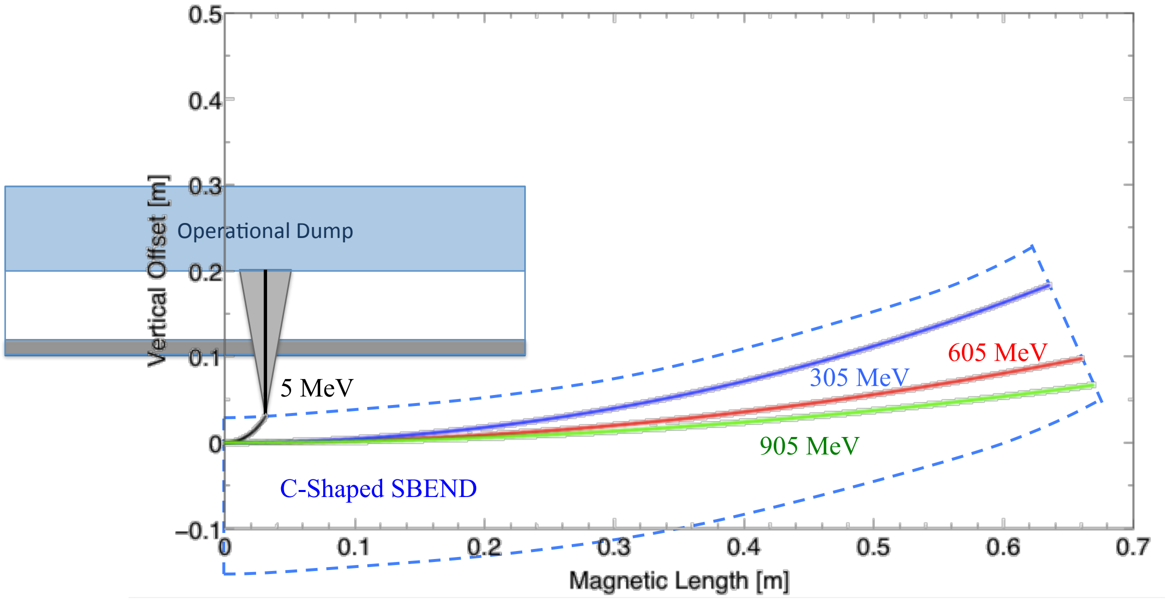
Graphite:
Sublimation temperature at 1atm - 3550 - 3825 °C
Density – 1.0 g/cm^3

These results show that the materials would melt when full electron beam consisting, hits the same locations on the dump.

Iron:
Melting temperature - 1538 °C
Density – 7.874 g/cm^3

Thus a beam dilution system will be an essential component for the extraction line of the PERLE.

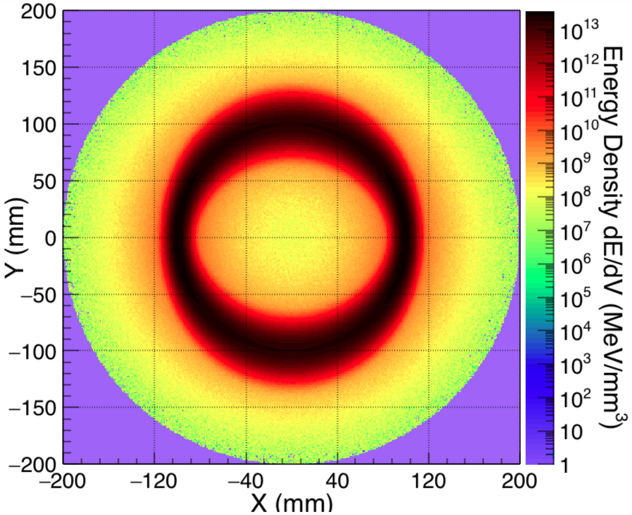
Dilution System



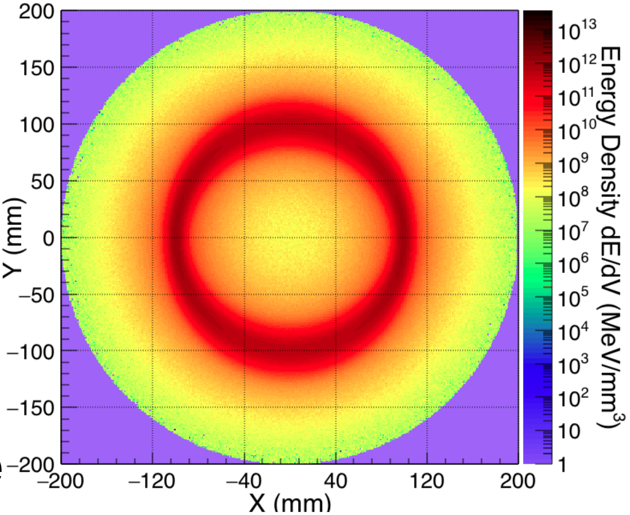
We have assumed 5m drift between the extraction dipole and dump, so there is space for a pair of orthogonal sweeping magnets to paint the beam on the dump.

But this means the dump becomes larger – if we paint the beam in a circle with a revolution period of 1 second, then that circle should have a radius of about 100 mm, to produce an effective beam area of about 3000 mm^2, compared to the 30 mm^2 in one spot.

Energy Deposition Transverse Profile depending on the depth (Fe)

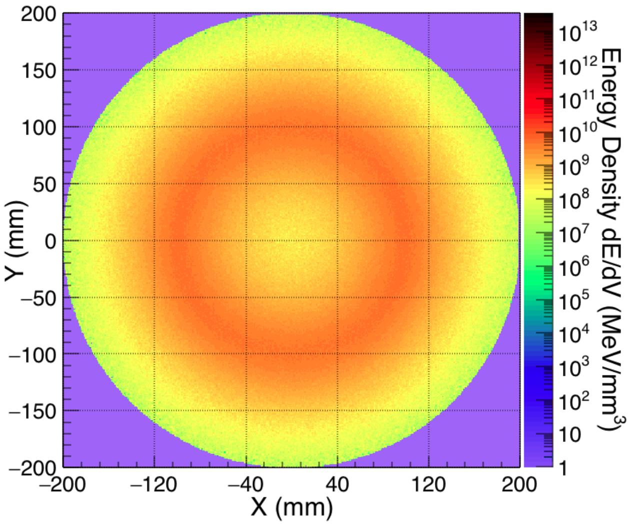


1 mm depth

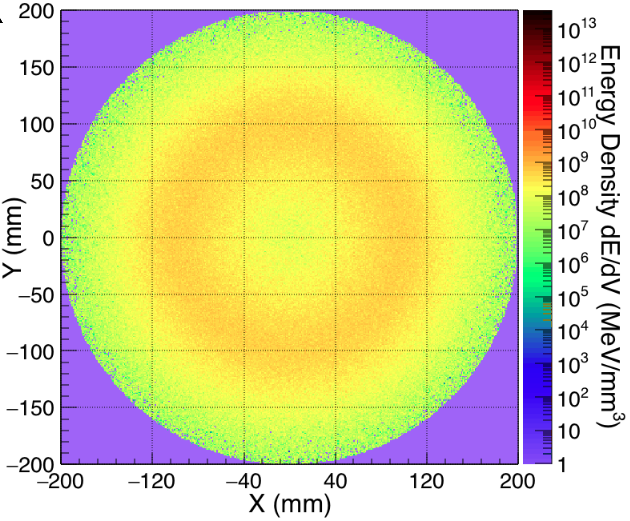


3 mm depth

In longitudinal direction (Z) we have 1mm thick transverse slice



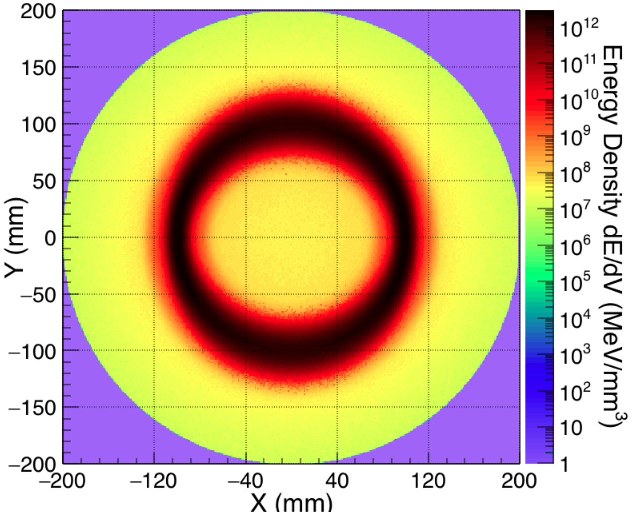
50 mm depth



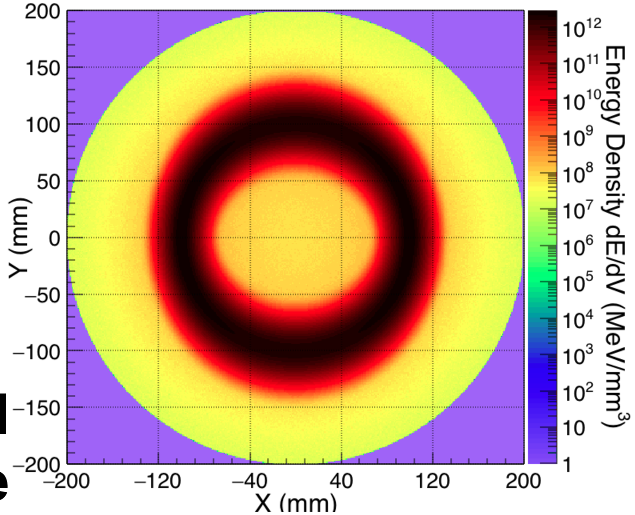
100 mm depth

Energy Deposition Transverse Profile depending on the depth (Gr)

1 mm depth

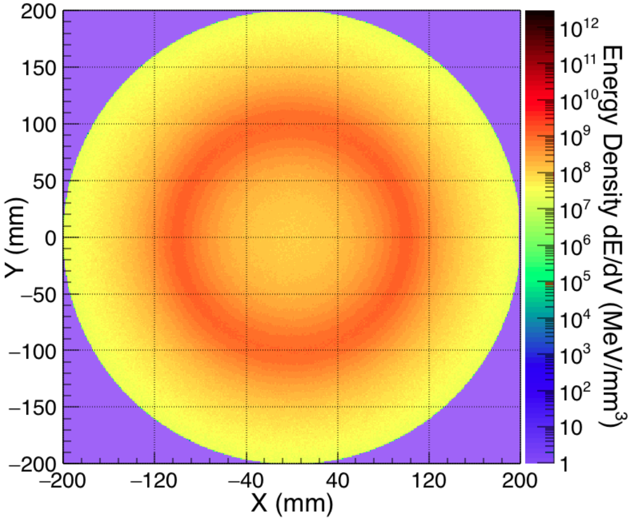


15 mm depth

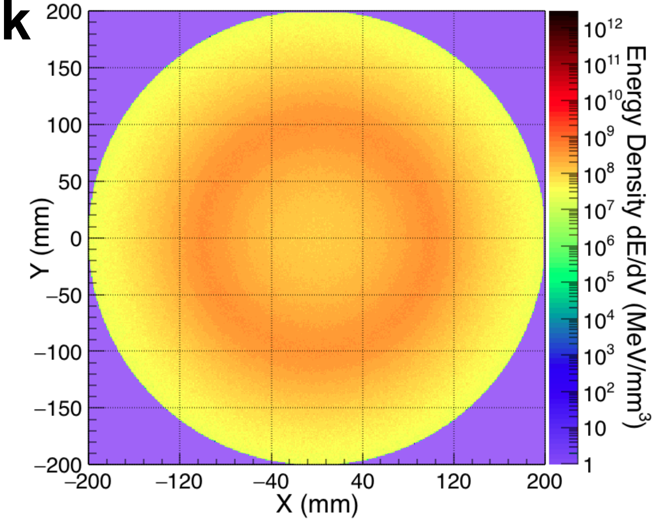


In longitudinal direction (Z) we have 1mm thick transverse slice

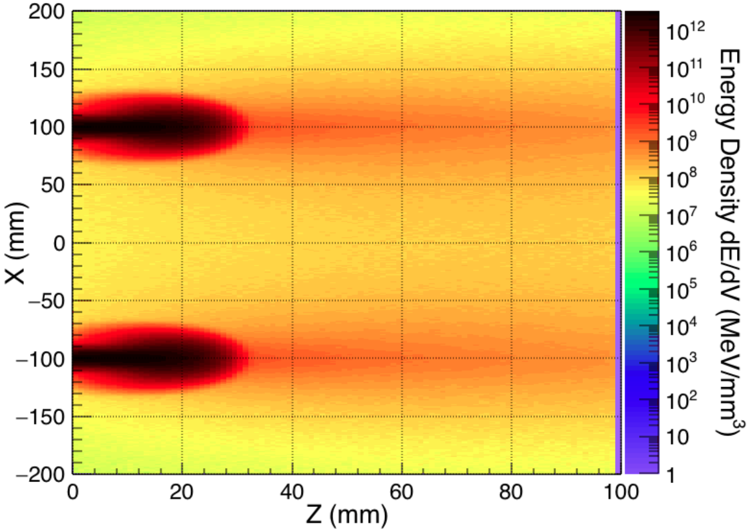
50 mm depth

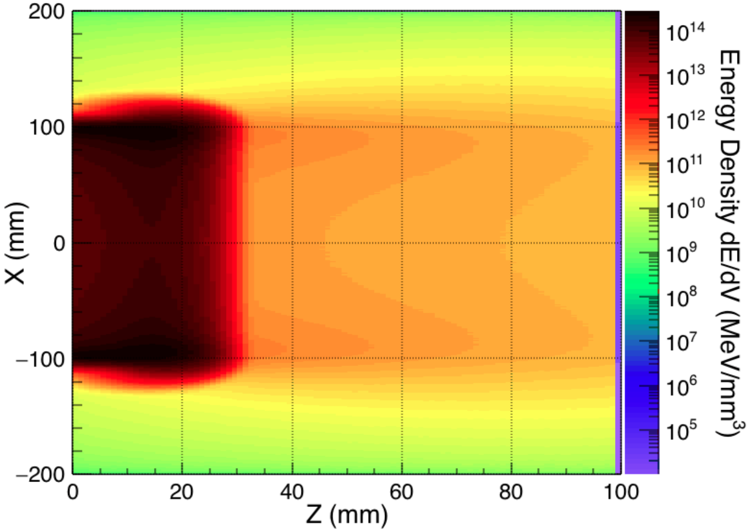


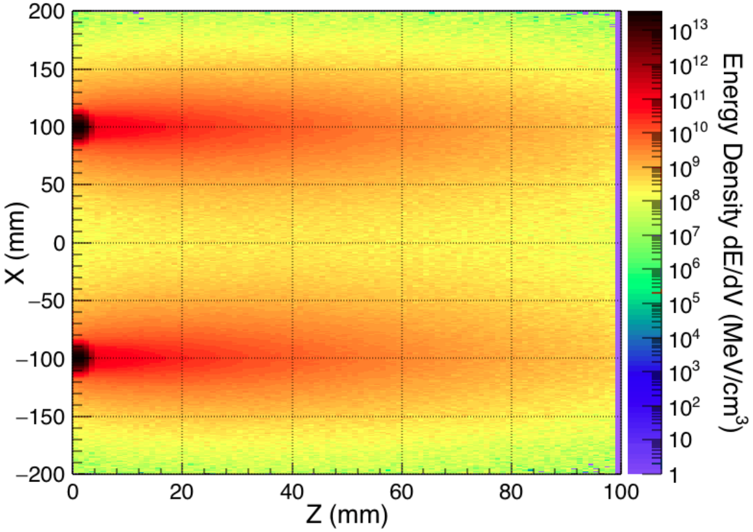
100 mm depth

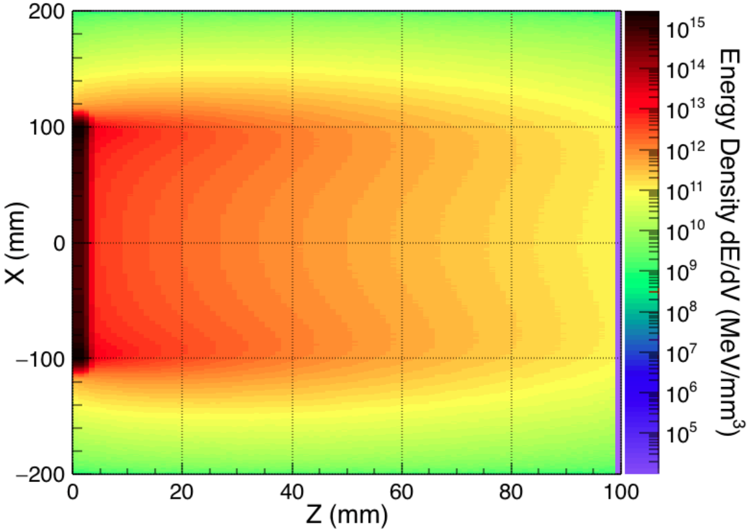


Longitudinal Profile of Energy Deposition

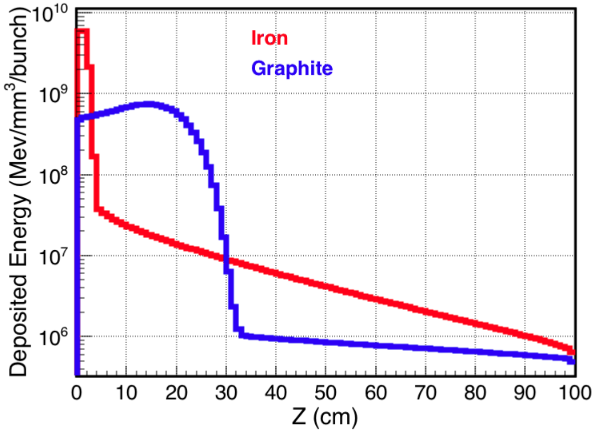


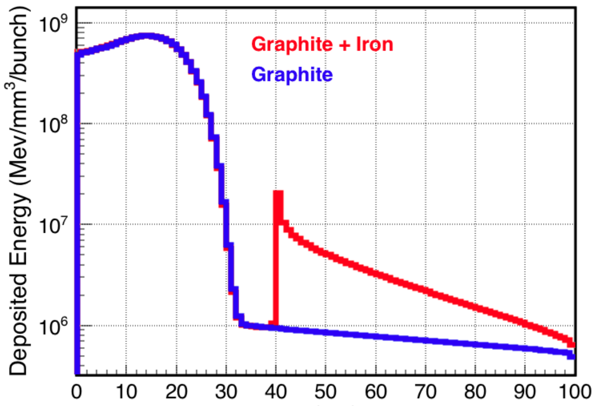






Penetration Depth of the Energy Deposition





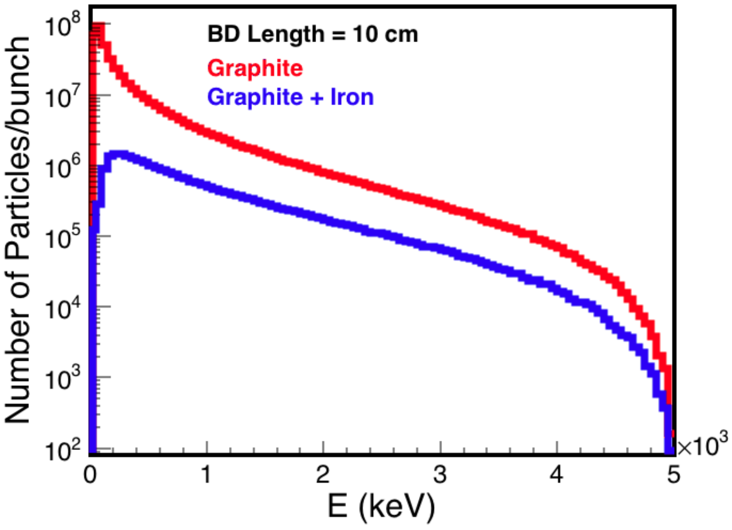
Longitudinal distribution of the deposited energy in Iron and Graphite absorbers.

We see long energy deposition tail until the end of absorber. The energy deposition value is dropped around thickness of 3.2 cm of the dump. But small energy deposition is still exist in the rest of the absorber.

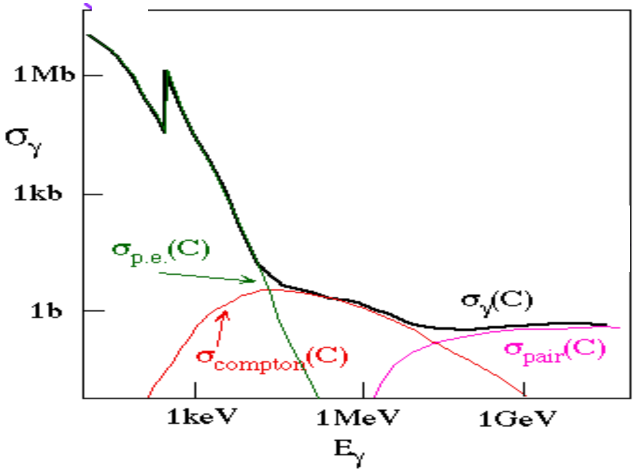
The maximum of the energy deposition occurs at a depth of ~15 mm for graphite and ~1-2 mm for iron absorbers.

The energy carried by the escaping particles for the Gr and Fe absorbers with 10cm length are the following: Fe ~ 0.17%, Gr ~ 0.38%.

Number of Particles Behind BD



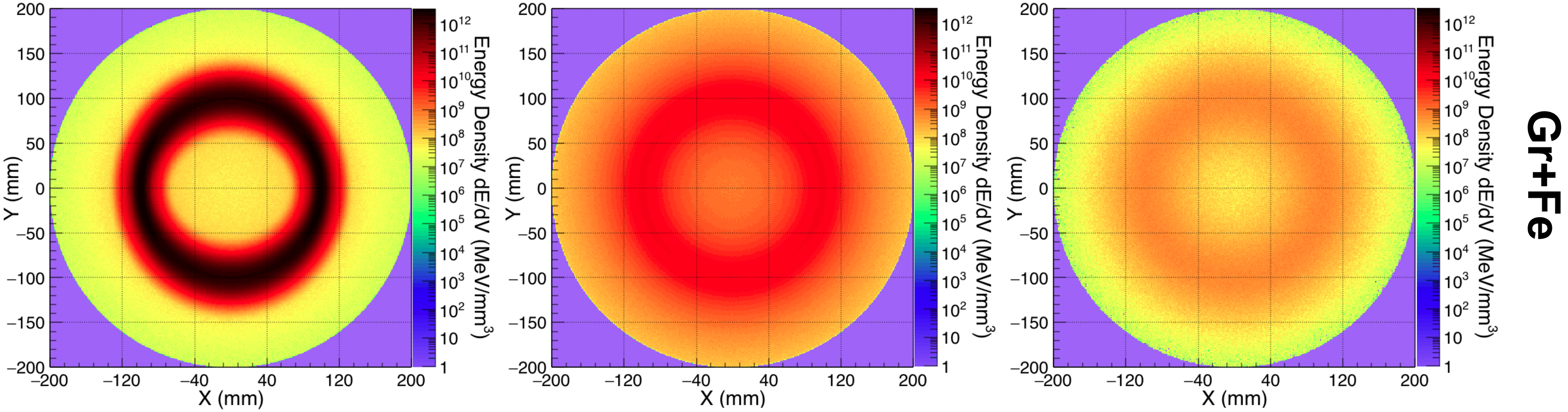
The spectra of the particles escaping the beam dump (BD) made by **Graphite** and **Gr+Fe**. Electrons loose the energy mainly in the first 3cm of the graphite absorber. The rest of the particles (mainly photons, but there are also a few electrons or positrons) deposit the small amount of energy in the rest of the absorber.



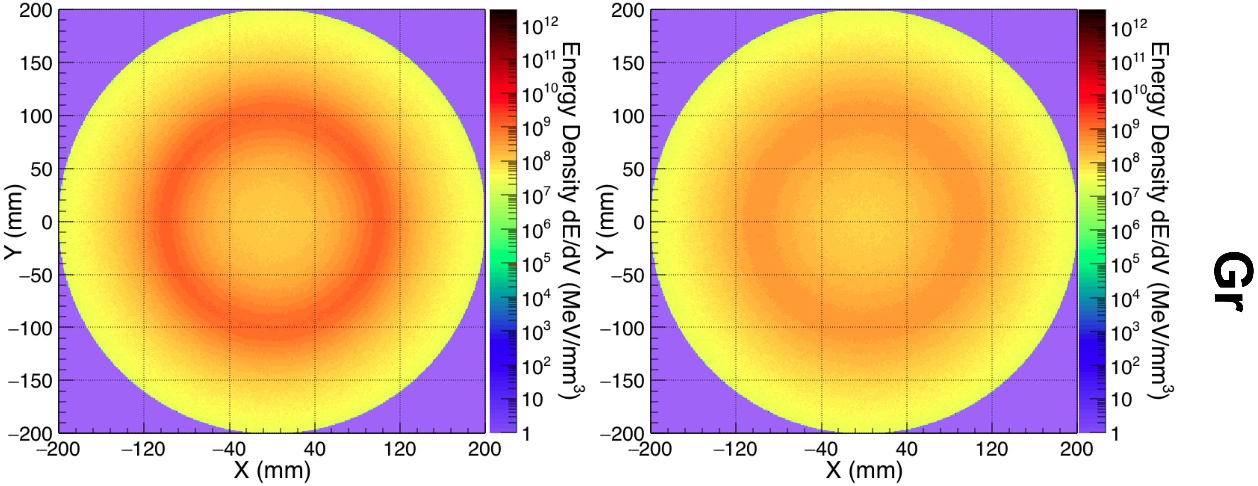
The only dominated process in the vicinity of 1MeV and less is the Compton scattering. But in Compton interaction photon is not disappeared. Only a portion of the photon energy is absorbed. A photon is produced with reduced energy.

Energy Deposition Transverse Profile depending on the depth (comparison)

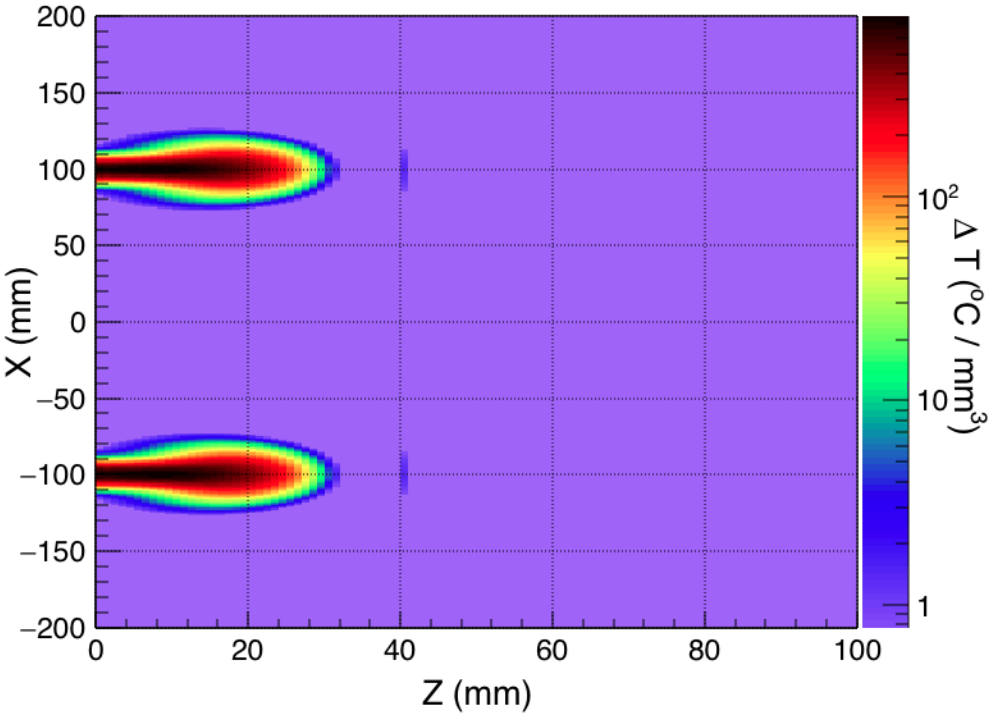
15 mm depth **50 mm depth** **100 mm depth**



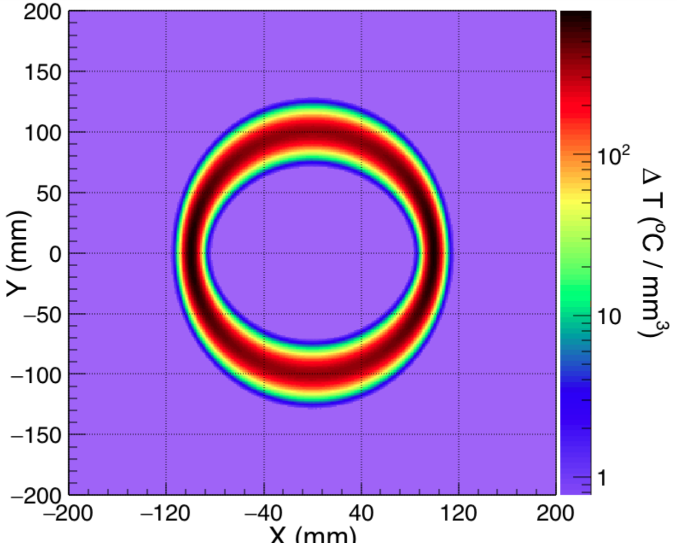
The energy deposition profiles in 1mm and 15 mm depths as is for the graphite



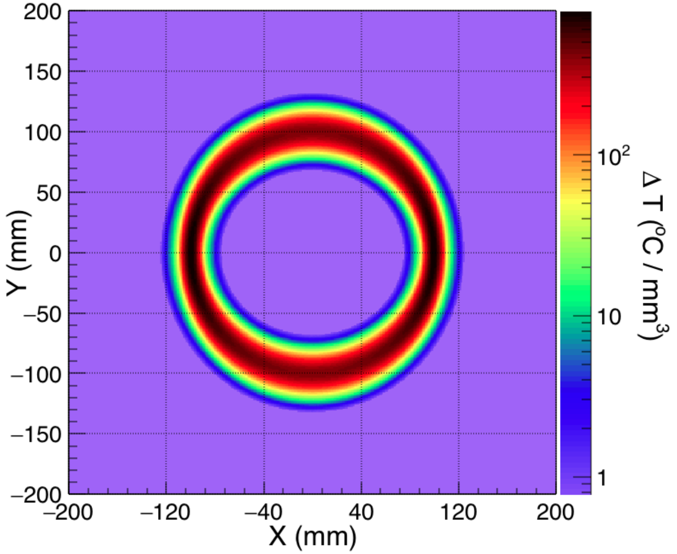
Temperature Distribution inside the BD



Temperature distribution in the longitudinal-vertical and transverse planes considering a 1 mm wide horizontal/vertical slices of BD from the center of the absorber.



1 mm depth



15 mm depth

Temperature rise (ΔT) in the beam dump

The maximum energy deposition density by the electron beam in 1 second in the low density (1g/cm^3) graphite is found to be 0.56 J/mm^3, which is equivalent to 570 J/g. The associated peak temperature rise in the graphite due to the impact of the beam of electrons in 1sec is 770.0 °C.

The maximum energy deposition density by the electron beam in 1 second in the iron is found to be 5.98 J/mm^3, which is equivalent to 800 J/g. The associated peak temperature rise in the iron due to the impact of of the beam of electrons in 1sec is 1680.0 °C.

These results show that iron made absorber would melt when electron beam distributed on a circle with 10 cm radius and consisting of 4*10^7 bunches hits the dump.

Summary

The energy deposition in different candidate absorber materials are examined and the detailed design studies have started for the PERLE operational dump, which needs to withstand 100kW beam power.

Future works:

1. **The simulation results reveal the necessity of a kicker-based dilution system, which will of course complicate the geometry.**
2. **The possibility to distribute the beam by spiral (a few coil) on the face of beam dump to reduce the temperature is foreseen.**
3. **Graphite absorber should be surrounded by iron one for reducing the remaining low energy particles.**

Summary

4. Checking the backscattered particles towards the recirculating beam from dump. If needed a thin layer of a heavy material should be installed at the entrance of the dump.
5. Some rationalization of the number of dumps and their functionality should still be made.
6. Beam dump study for high energy electrons.
7. Detailed thermo-mechanical stress calculations for the beam dump.