Beam loss simulation along the CLIC Main Line and prediction of damages to electronics

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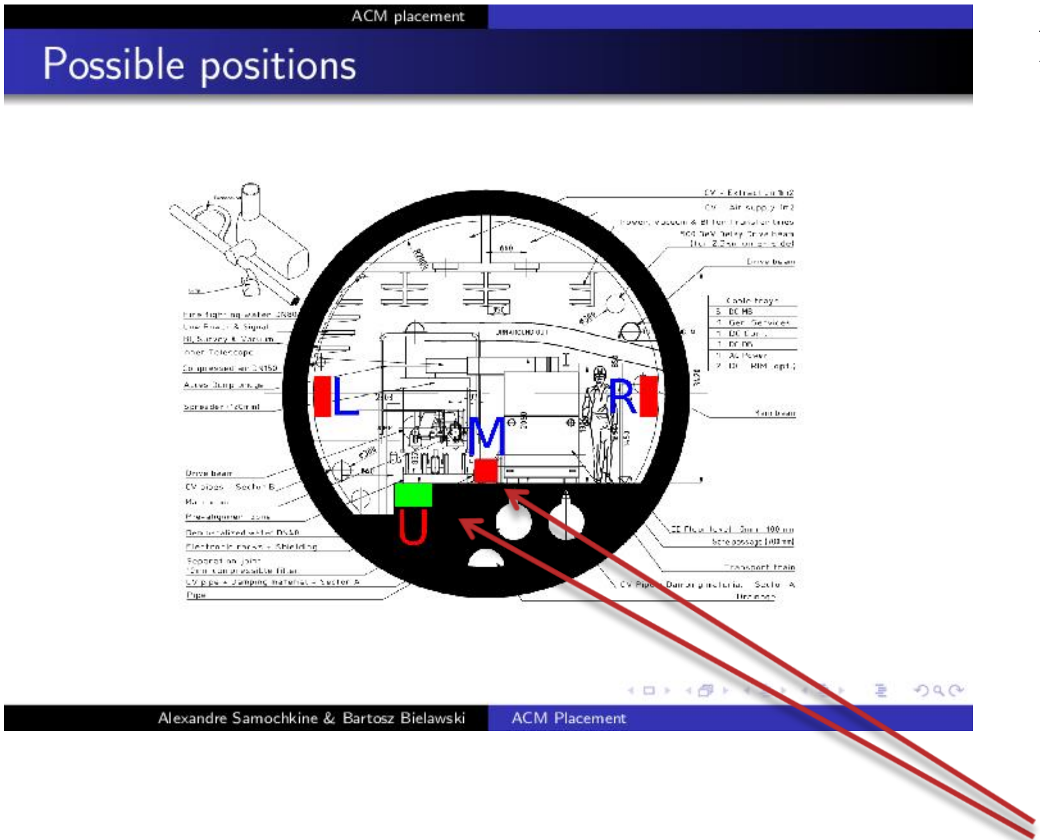
Preface

The present study aims in estimating damages to electronic units installed at various locations inside the CLIC main linac tunnel using Monte-Carlo simulations.

Some technical details, advantages and disadvantages of possible placements for the units were described in:

- https://edms.cern.ch/file/1218696/1/annex_5_CLIC-Module_Layout.pptx
- https://edms.cern.ch/file/1225327/3/DRAFT_CLIC-Tunnel_ACM-placement.xlsx

Preface and notations



Possible placements for electronics units
(the picture was taken from B.Bielawski and A.Samochkine presentation)

After preliminary simulations and TBM Working Group proposals:
Two possible placements for the electronics units were chosen: in the middle of the tunnel and under the Drive beam line (marked on the picture as “M” and “U”).

Below in the document the following notations are used: letters U or M – for the electronics unit’s placement indications or for the results related to these regions of interest; DB and MB means CLIC “Drive beam” or “Main beam” respectively.

Beam parameters

- Main beam: 1.16E+12 particles per bunch; 50 bunches per second; Drive beam: 1.54E+14 particles per bunch; 50 bunches per second; Total beam losses: 0.001 for the Drive beam; 1.0e-5 for the Main beam; Number of quadrupoles: 2010 for the Main beam; 20924 for the Driven beam (CLIC CDR).
- 200 days of full operation per year.
- Beam loss patterns: particles are being lost at the point of the beginning of the magnetic field region of each quadrupoles and the losses are uniformly distributed along the linac; total number of primaries striking to quadrupole's aperture per second: 3.7E+8 for DB line and 2.9e+5 for MB line.

Geometry for simulation

- The preexisting geometry of MB and DB quadrupoles (created by Sophie Mallows) was used
- Complete geometry for beam lines have been constructed according to the magnetic optics ("optics" files provided by Andrea Latina (CERN))
- The magnetic field in the quads have been linked with the "optics" files

The simulation's procedure

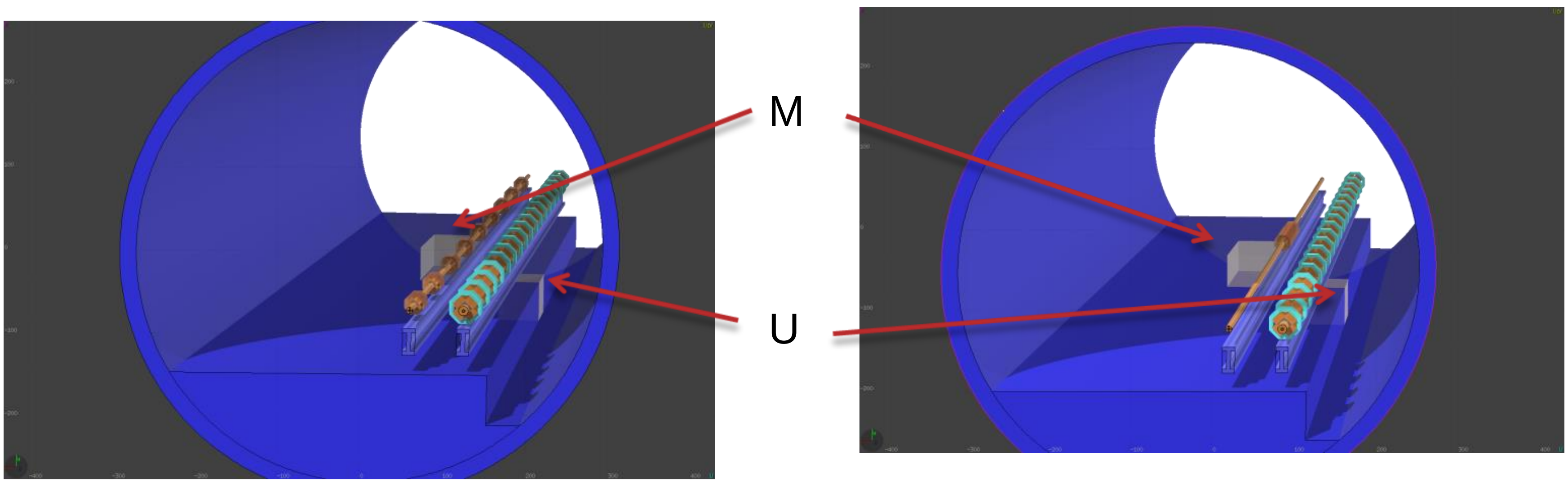
- Two-step method was used for the simulations (C. Theis 2006):
- First step:

  simulation with a complete geometry (18 m - long sections; 9 Two Beam Modules) to collect secondaries particles in the regions of interest .
- Second step:

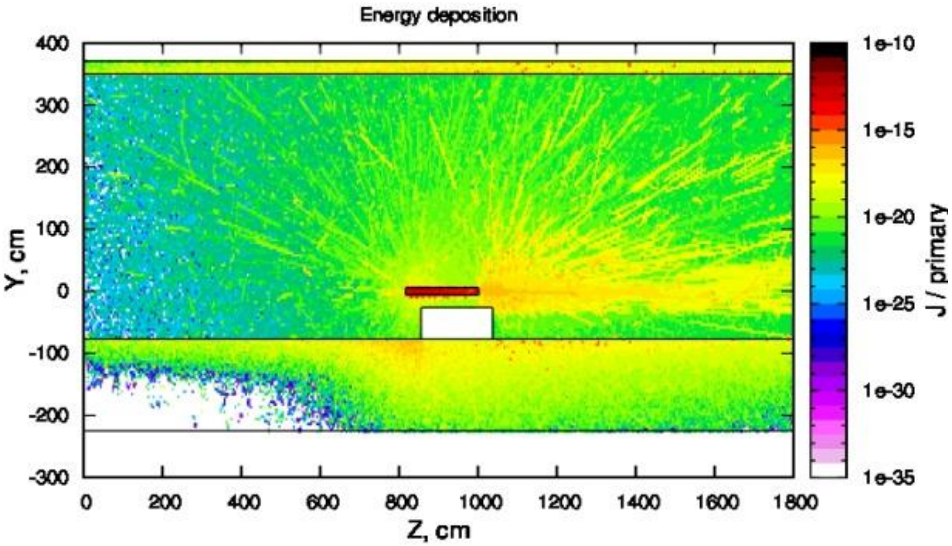
  simulation with a complete or reduced geometry using collected particles from the first step as a source. This approach allows to provide acceptable statistic in the regions of interest and make geometry optimization.

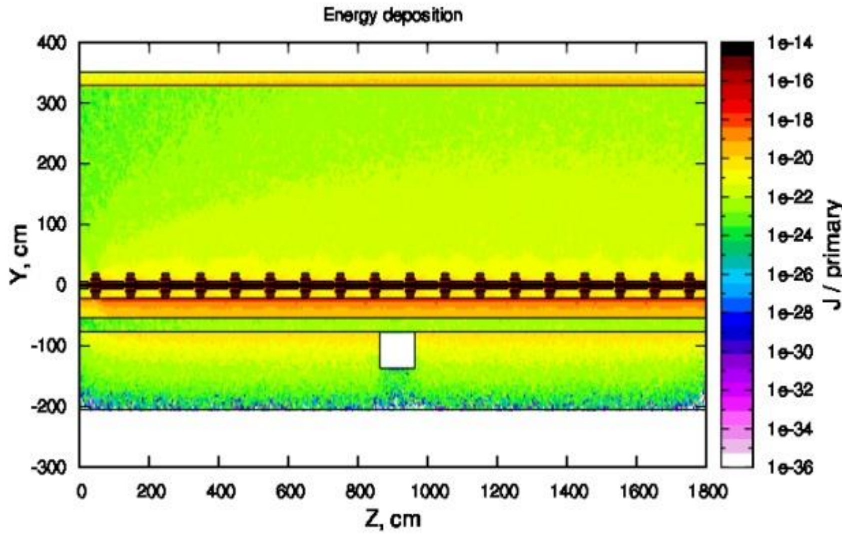
The simulation's procedure: first step

Four simulations were done for the first step: DB energy – 2.4 GeV; MB energy – 10.0 GeV; DB energy – 0.24 GeV; MB energy – 1.5 TeV.



CLIC tunnel geometry: 0-18 meters (9 TBM Type1); 209981 – 209999 meters 4 TBM type0 + 1 TBM type4 + 4 TBM type0



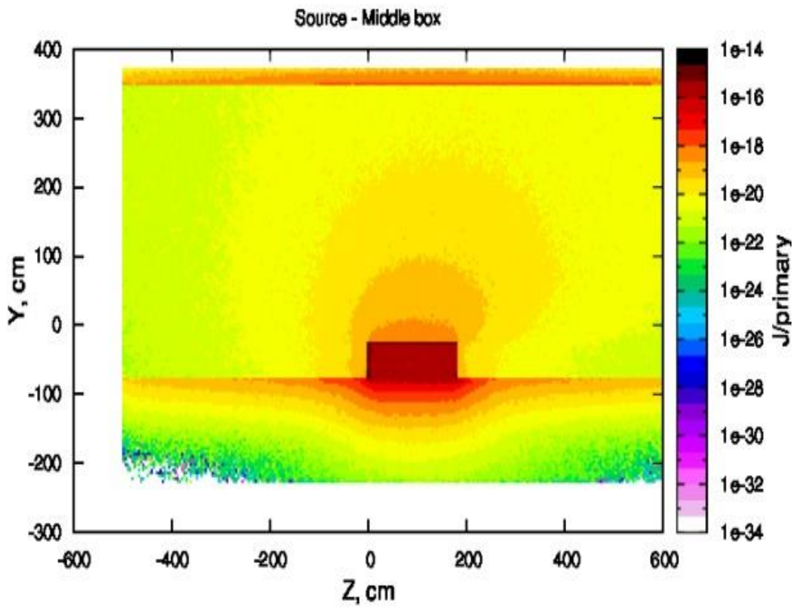


left – produced by MB with energy 1.5 TeV;
right – DB with energy 2.4 GeV.

Pictures from the first step: the slices of 3D-binning energy deposition in the geometry. "White regions" in the center are representing the regions of interest where all secondaries particles were collected.

The simulation's procedure: second step

Second step: simulation with a reduced geometry (no quadrupoles – to simplify a geometry without affect on the final results).



The electronic modules were simulated as air-filled boxes (to avoid a self-shielding effect). Each “module” has a volume 168000 cm3 (40x30x140cm3 – position M; 42x40x100 – position U). The shielding was simulated as additional layer of material surrounding the electronic module.

Results: calculated quantities

- Calculated quantities:

  For the cumulative damages:

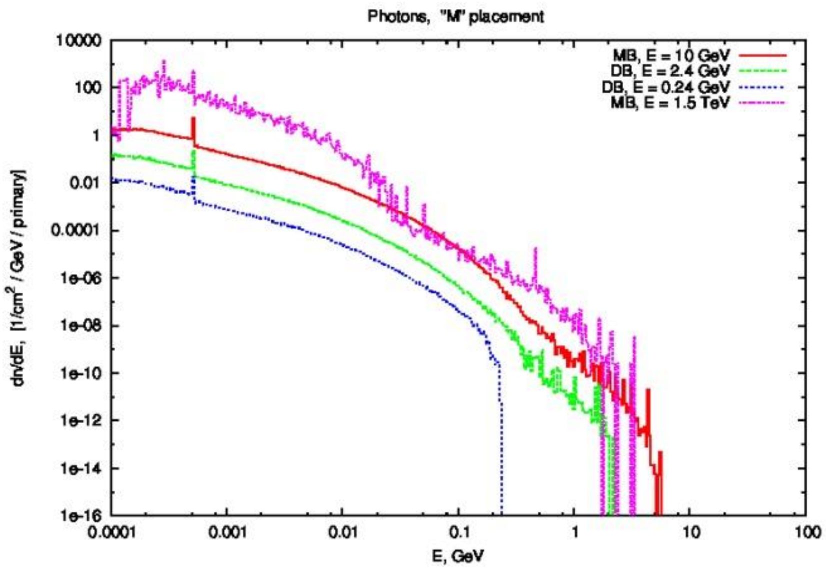
  The damages by ionizing radiation was estimated by calculating the total ionizing dose;

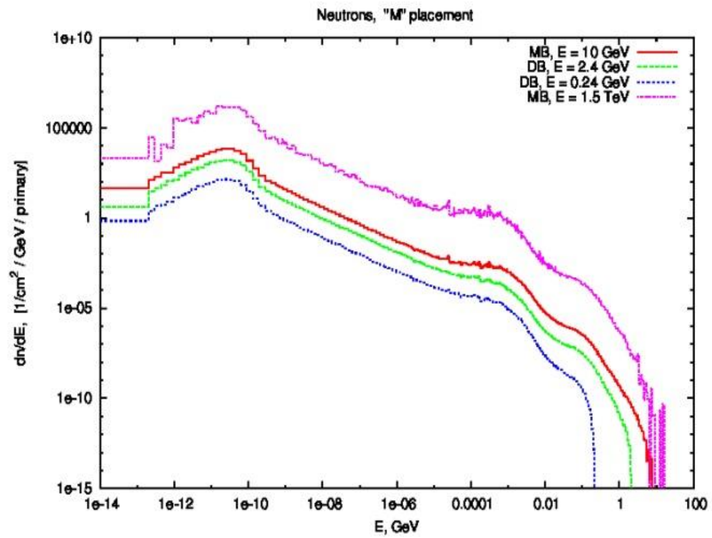
  Si lattice displacement was estimated by calculating the 1 MeV neutron equivalent particle fluxes;

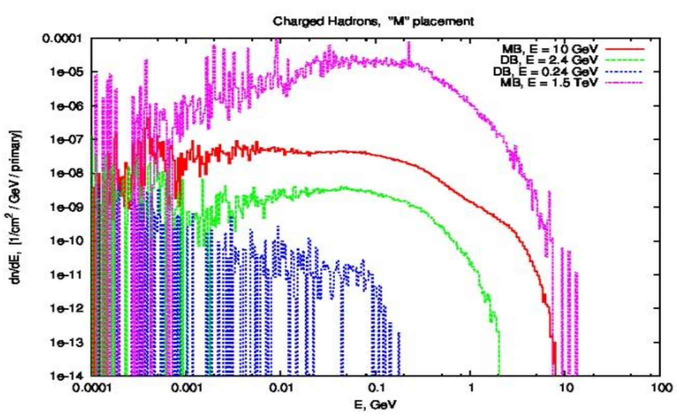
  Stochastic failures were estimated by calculating the high (>20 MeV) energy hadron fluences.

- The scoring was made in a 3D mesh covering the volume of interest with a bin-size of (approximately) 2.5x2.5x2.5 cm^3.
- Average value – distribution integrated over the volume

Results: Spectra of secondaries



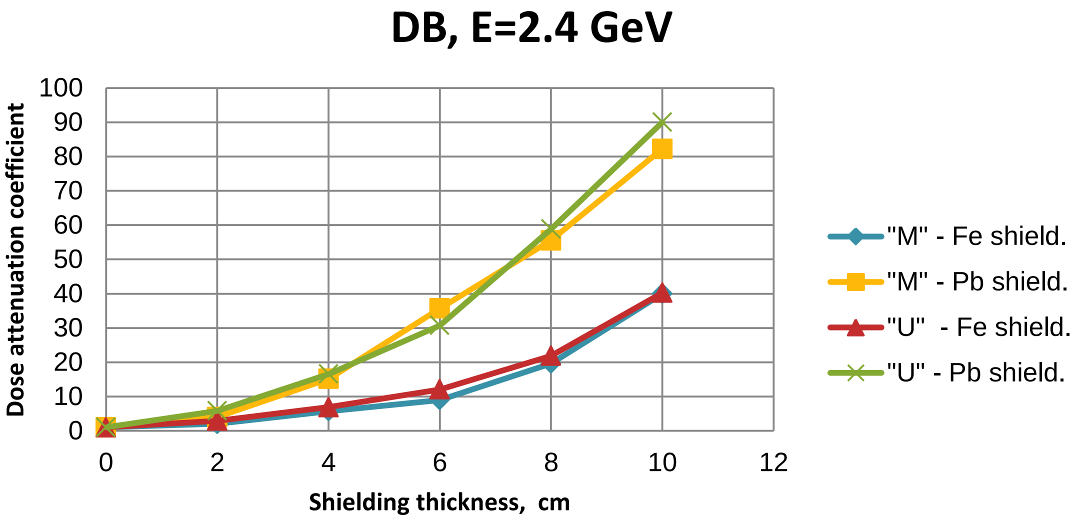




Particle's fluences in the region "M":
Left: photon's energy spectra;
Right: neutrons;
Bottom: charged hadrons.

Results: Material for shielding Pb and Fe

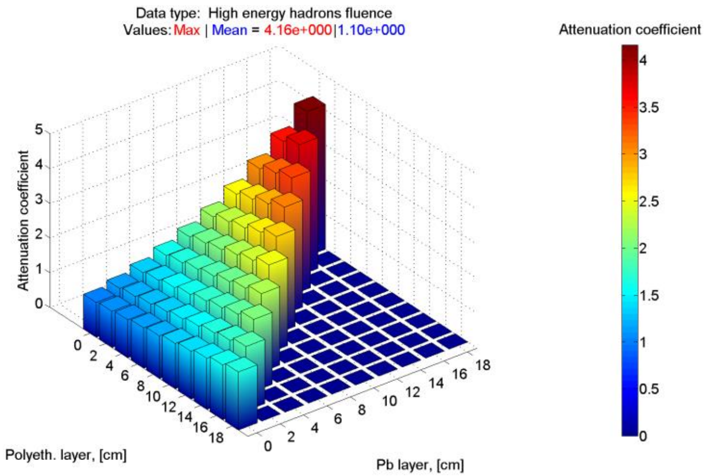
Dependence of Dose attenuation coefficient (for average dose) on shielding material and shielding thickness

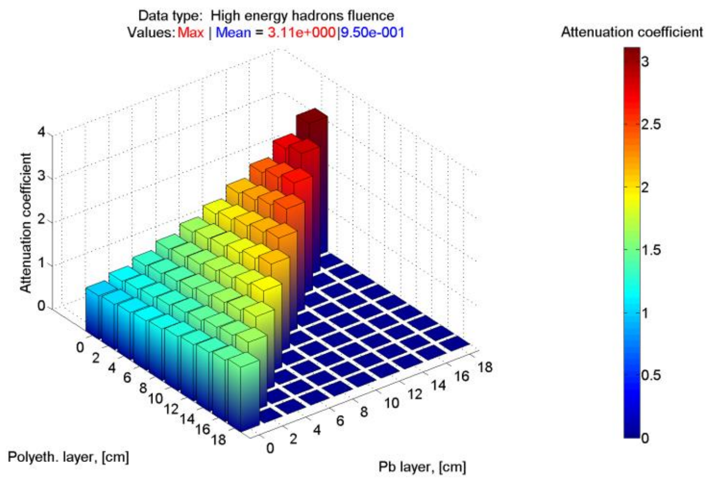


materials works equally.

Pb is more effective than Fe on factor of ~ 2.5.

Results: Materials combinations for shielding



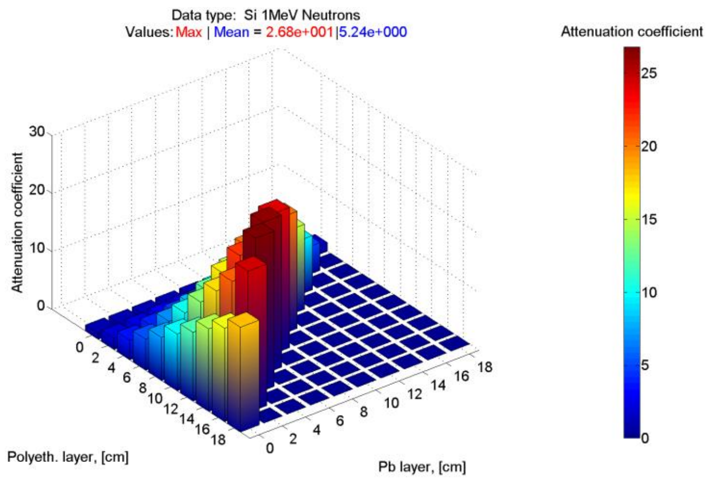


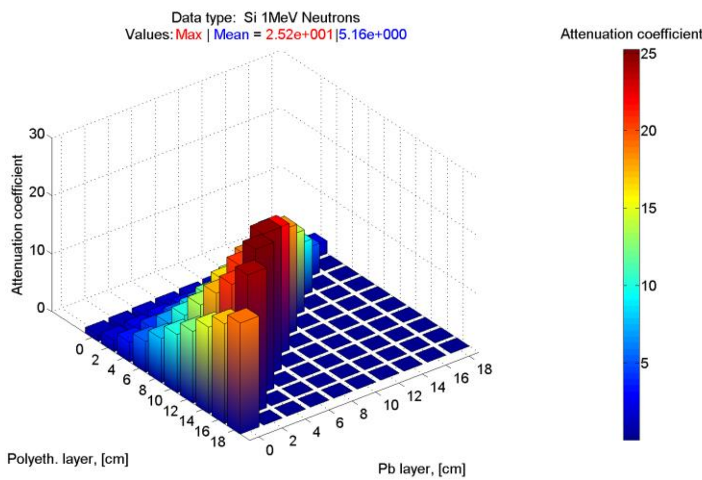
Average attenuation coefficient for the high (>20 MeV) energy hadron fluences:

Locations: M – top; U – bottom

Primary beam: DB 2.4 GeV

Results: Material for shielding combinations

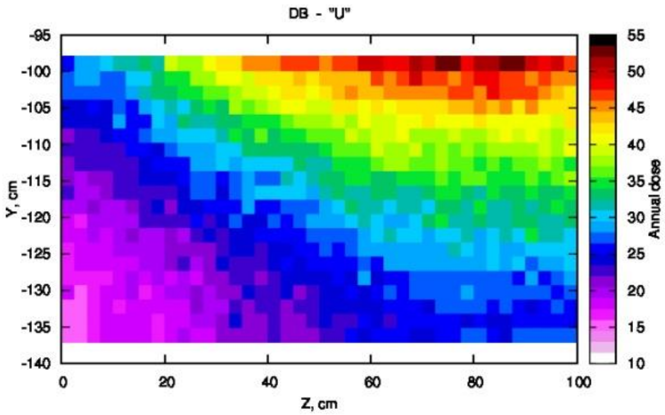


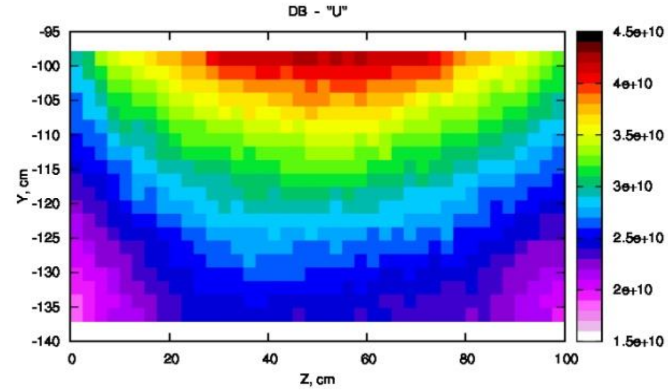


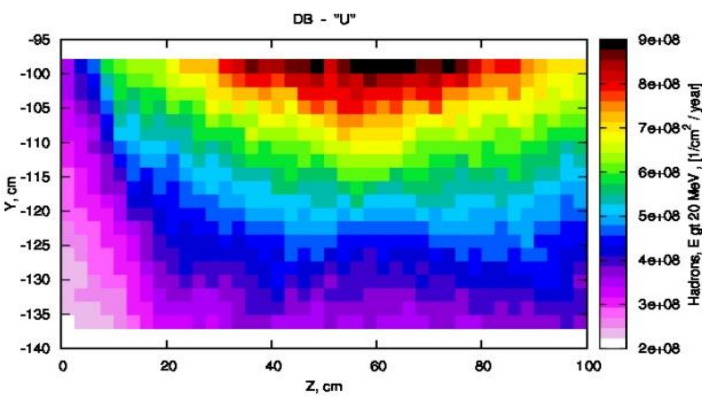
Average attenuation coefficient for Si lattice displacement 1 MeV neutron equivalent: Locations: M – top; U – bottom

The same set of simulations as above was made for Fe-Polyethylene shielding. This type of shielding is on 10% more effective in neutron flux attenuation if compare with Pb-Polyethylene.

Results: Estimation of the values related to damages of electronics – 3D mesh







Primary beam: DB 2.4 GeV; Position U
Top Left: dose 2D vertical profile;
Top Right: Si lattice displacement 1 MeV neutron equivalent flux 2D vertical profile;
Left Bottom: high (>20 MeV) energy hadron fluence 2D vertical profile.

Results: Estimation of the values related to damages of electronics – maximal values 1

DB, Energy 2.4 GeV – influences on electronics

Shielding type	Energy [GeV] / Beam type	Module position	Dose, [Gy/year]	Dose, Stat.err%	Si-1-MeV-N, 1/cm^2/year	Si-1-MeV-N, Stat.err%	Ch. Hadr, 1/cm^2/year	Ch. Hadr, Stat.err%
No	2.4/DB	U	97	10	7.28E+10	30	1.85E+09	30
No	2.4/DB	M	97	18	4.85E+10	30	1.48E+09	30
Pb/10cm	2.4/DB	U	8*	-	2.72E+10	30	5.98E+08	30
Pb/10cm	2.4/DB	M	11*	-	4.74E+10	30	7.39E+08	30

*– estimation (stat. error > 30 %)

- Stat error = 30% - Upper limit for the value

Results: Estimation of the values related to damages of electronics – maximal values 2

DB, Energy 0.24 GeV – influences on electronics

Shielding type	Energy [GeV] / Beam type	Module position	Dose, [Gy/year]	Dose, Stat.err%	Si-1-MeV-N, 1/cm^2/year	Si-1-MeV-N, Stat.err%	Ch. Hadr, 1/cm^2/year	Ch. Hadr, Stat.err%
No	2.4/DB	U	10	11	5.65E+09	30	4.89E+07	30
No	2.4/DB	M	6	16	3.91E+09	30	3.76E+07	30
Pb/10cm	2.4/DB	U	<1*	-	2.31E+09	30	1.36E+07	30
Pb/10cm	2.4/DB	M	<1*	-	3.32E+09	30	1.02E+07	30

*– estimation (stat. error > 30 %)

- Stat error = 30% - Upper limit for the value

Results: Estimation of the values related to damages of electronics – maximal values 3

MB, Energy 1.5 TeV – influences on electronics

Shielding type	Energy [GeV] / Beam type	Module position	Dose, [Gy/year]	Dose, Stat.err%	Si-1-MeV-N, $1/cm^2$/year	Si-1-MeV-N, Stat.err%	Ch. Hadr, $1/cm^2$/year	Ch. Hadr, Stat.err%
No	2.4/MB	U	6	24	2.78E+10	30	1.65E+09	30
No	2.4/MB	M	14*	22	3.96E+10	30	1.21E+09	30

*– Average over the bin size of 12.5x12.5x12.5 cm^3

- Stat error = 30% - Upper limit for the value

Conclusion

Shielding studies were performed for average values (integrated over investigated volume):

- Lead and iron as the shielding material in combinations with a polyethylene were investigated. Lead is more effective in dose attenuation than iron on factor of ~ 2.5; 10 cm of lead can provide dose attenuation on factor of ~ 80.
- The additional 12-14 cm layer of polyethylene will reduce Si displacement 1-MeV neutron equivalent particles flux by factor of 20-25.
- Although Boron-Polyethylene almost doesn't affect on neutrons fluxes above 1 MeV, it will affect significantly on low energy part (thermal and epithermal neutrons are important for SEU)

Doses: for the chosen beam loss scenario total ionizing doses will not exceed 100 Gy/year for DB and ~ 15 Gy/year for MB

Single events effects have to be studied separately.

Thank you for your attention!