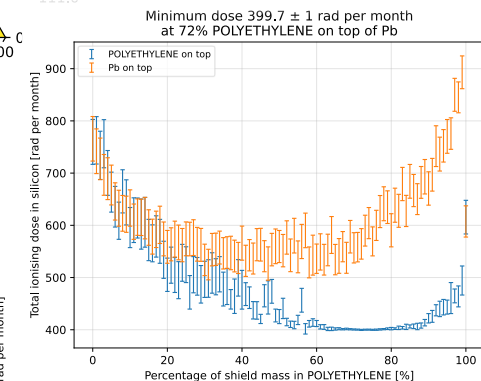
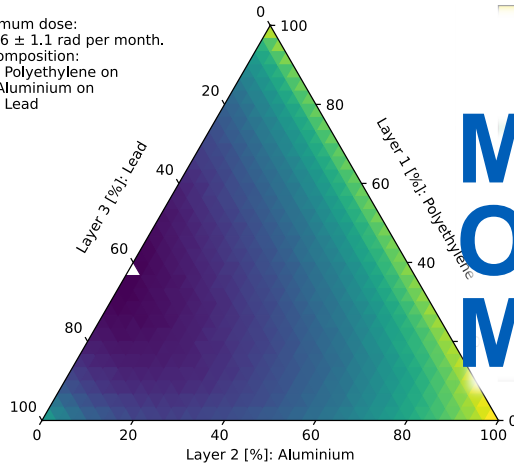
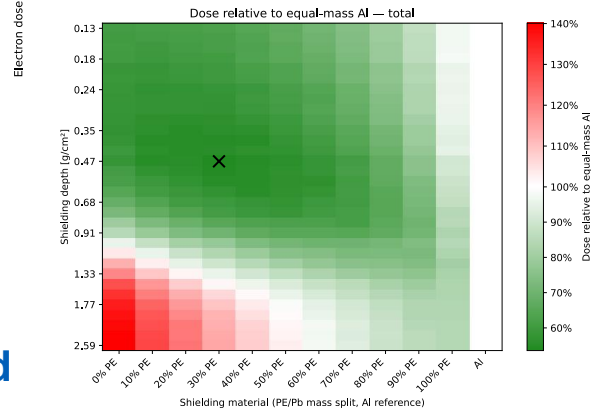
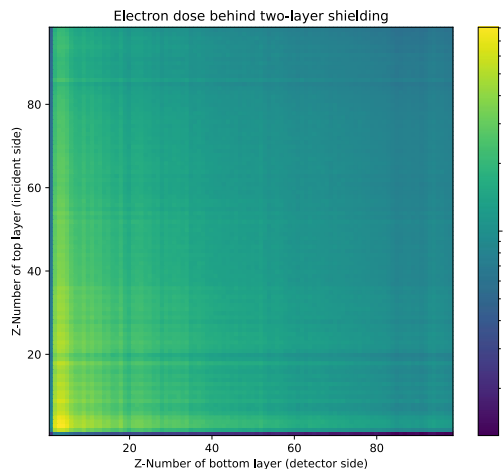
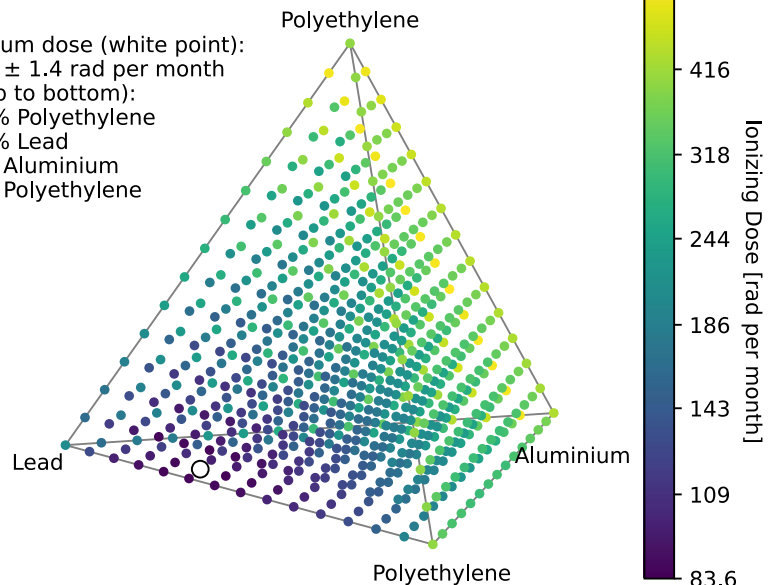


Multilayer Radiation Shielding Optimisation with GRAS and MULASSIS

Minimum dose:
 110.6 ± 1.1 rad per month.
 At composition:
 38% Polyethylene on
 0% Aluminium on
 62% Lead



Minimum dose (white point):
 83.61 ± 1.4 rad per month
 at (top to bottom):
 28.6 % Polyethylene
 64.3 % Lead
 7.1 % Aluminium
 0.0 % Polyethylene



Anton Fetzer
PhD student at
Aalto University, Finland

GRAS & MULASSIS

In common:

- Developed through ESA
- Monte Carlo particle transport through matter
- Radiation-shielding analysis
- Scoring TID, NIEL, and

- GRAS also has a “MULASSIS mode”

In the following:

GRAS = GRAS in GDML mode

MULASSIS = MULASSIS or GRAS in MULASSIS mode

Geant4 Radiation Analysis for Space

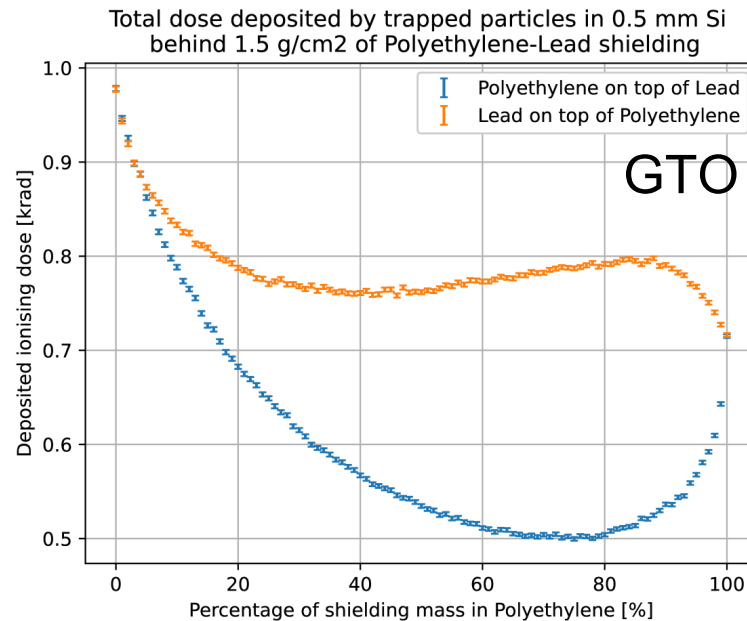
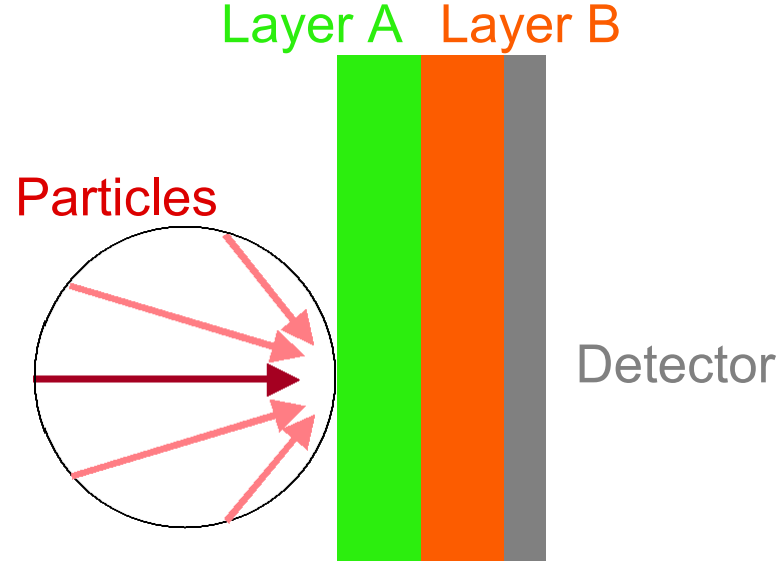
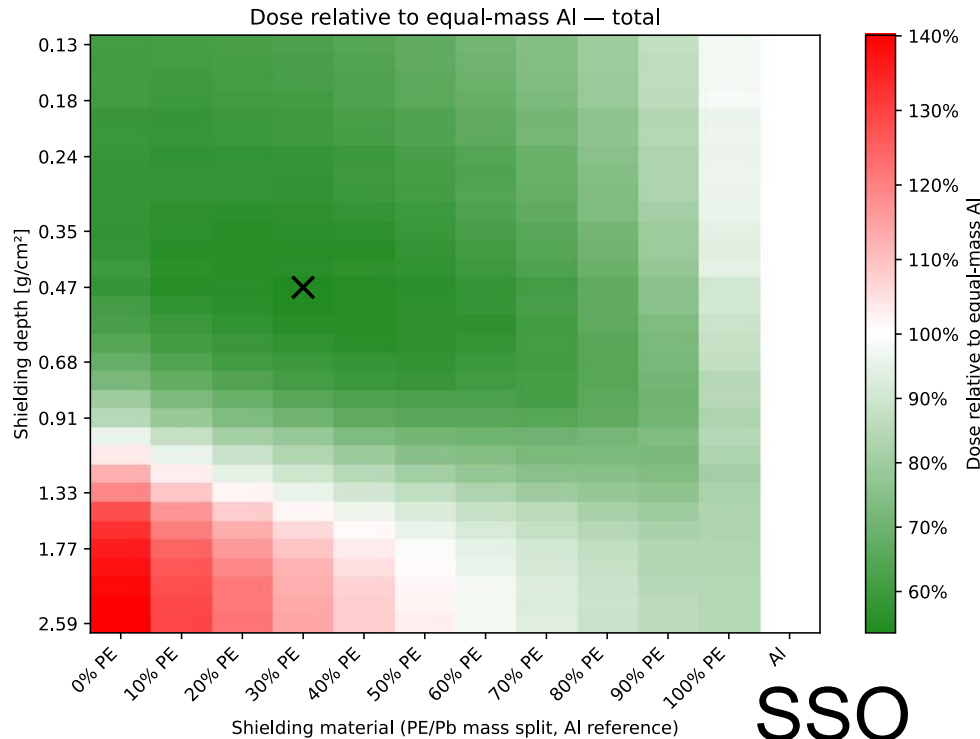
- Full 3D geometries defined in GDML
- General purpose radiation analysis

MULti-LAYer Shielding Simulation Software

- 1D multi-layer stacks defined in macro
- Purpose-built for multilayer stacks

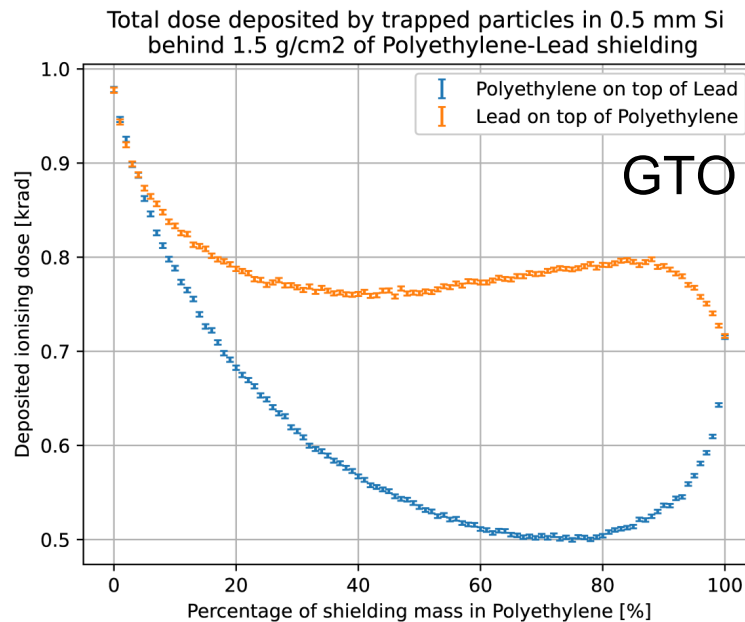
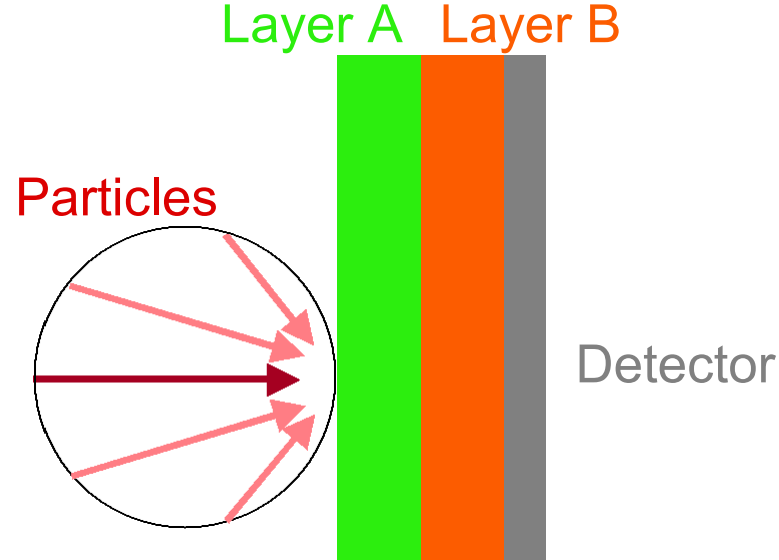
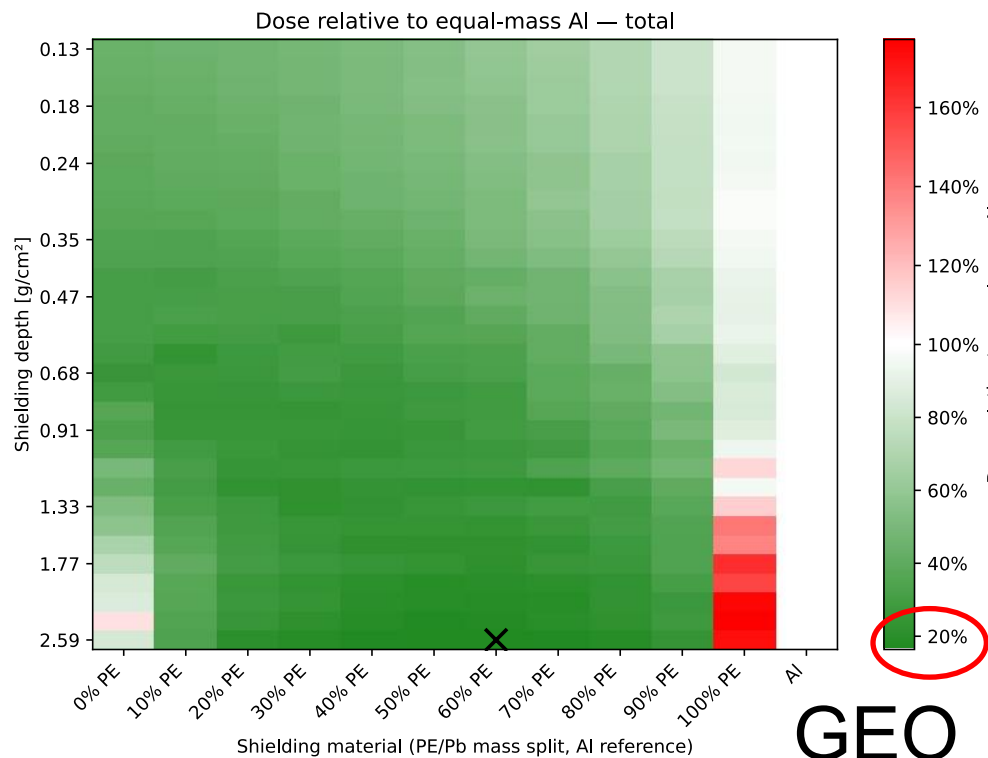
Multilayer Optimisation Overview

- Combining different materials can improve shielding performance



Multilayer Optimisation Overview

- Combining different materials can improve shielding performance



Multilayer Optimisation Overview

- Combining different materials can improve shielding performance
- Has been done since the 1950's
- Depends strongly on the particle spectra and shielding requirements
- Infinite number of materials
- Infinite number of permutations
- Systematic approach needed to explore the parameter space

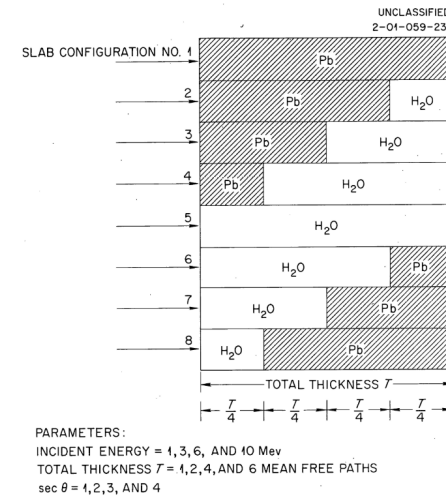


Fig. 1. Stratified Slab Configurations.

L. A. Bowman and K. Trubey, "Stratified Slab Gamma-Ray Dose-Rate Buildup Factors for Lead and Water Shields," Jan. **1958**. DOI: 10.2172/4330882

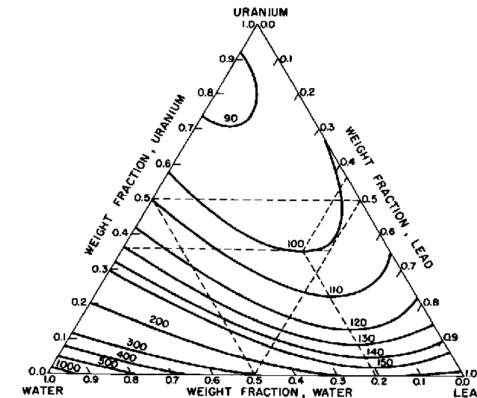


Fig. 5. Weight variation of uranium-lead-water shield.

A. F. Rohach, "Weight Optimization of Gamma-Ray Shields Using Layered Media and Spherical Geometry," *Nuclear Science and Engineering*, vol. 27, no. 2, pp. 464–466, Feb. **1967**, doi: 10.13182/nse67-a18285.

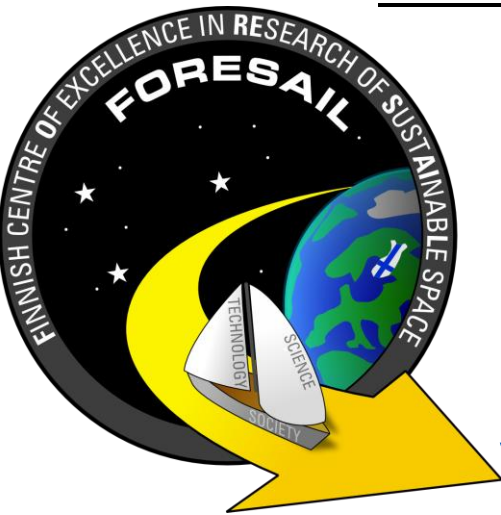
Multilayer Optimisation

Overview

- Combining different materials can improve shielding performance
- Has been done since the 1950's
- Depends strongly on the particle spectra and shielding requirements
- Infinite number of materials
- Infinite number of permutations
- Systematic approach needed to explore the parameter space

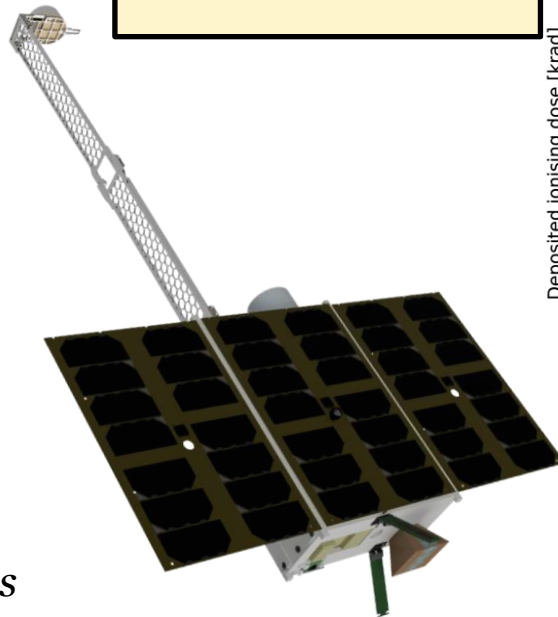
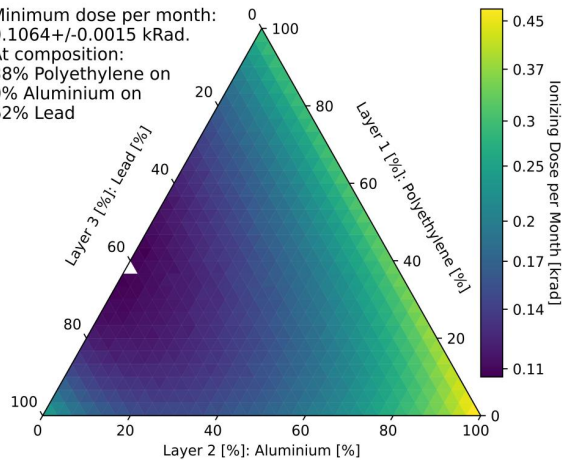
2-Step approach:

1. Simulate permutations of materials in layers of equal mass to identify suitable material combinations
2. Vary the mass ratio between suitable materials to find the optimum

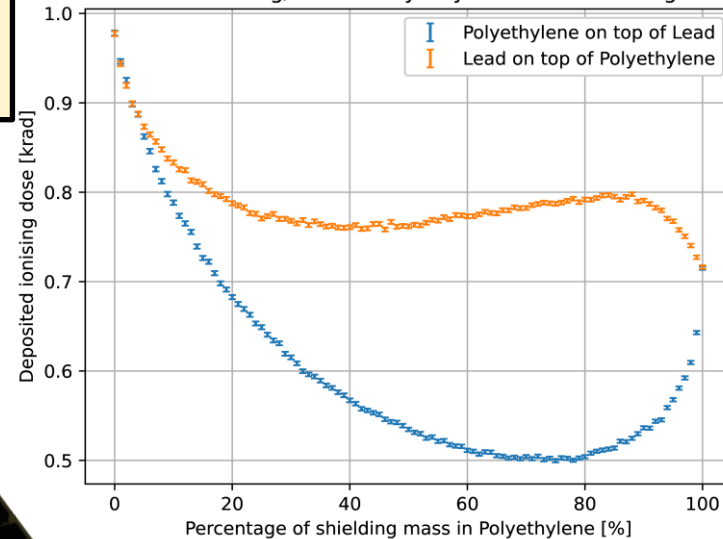


Multilayer Radiation Shielding Optimisation with GDML

Minimum dose per month:
0.1064 +/- 0.0015 kRad.
At composition:
38% Polyethylene on
0% Aluminium on
62% Lead



Total dose deposited by trapped particles in 0.5 mm Si behind 1.5 g/cm² of Polyethylene-Lead shielding

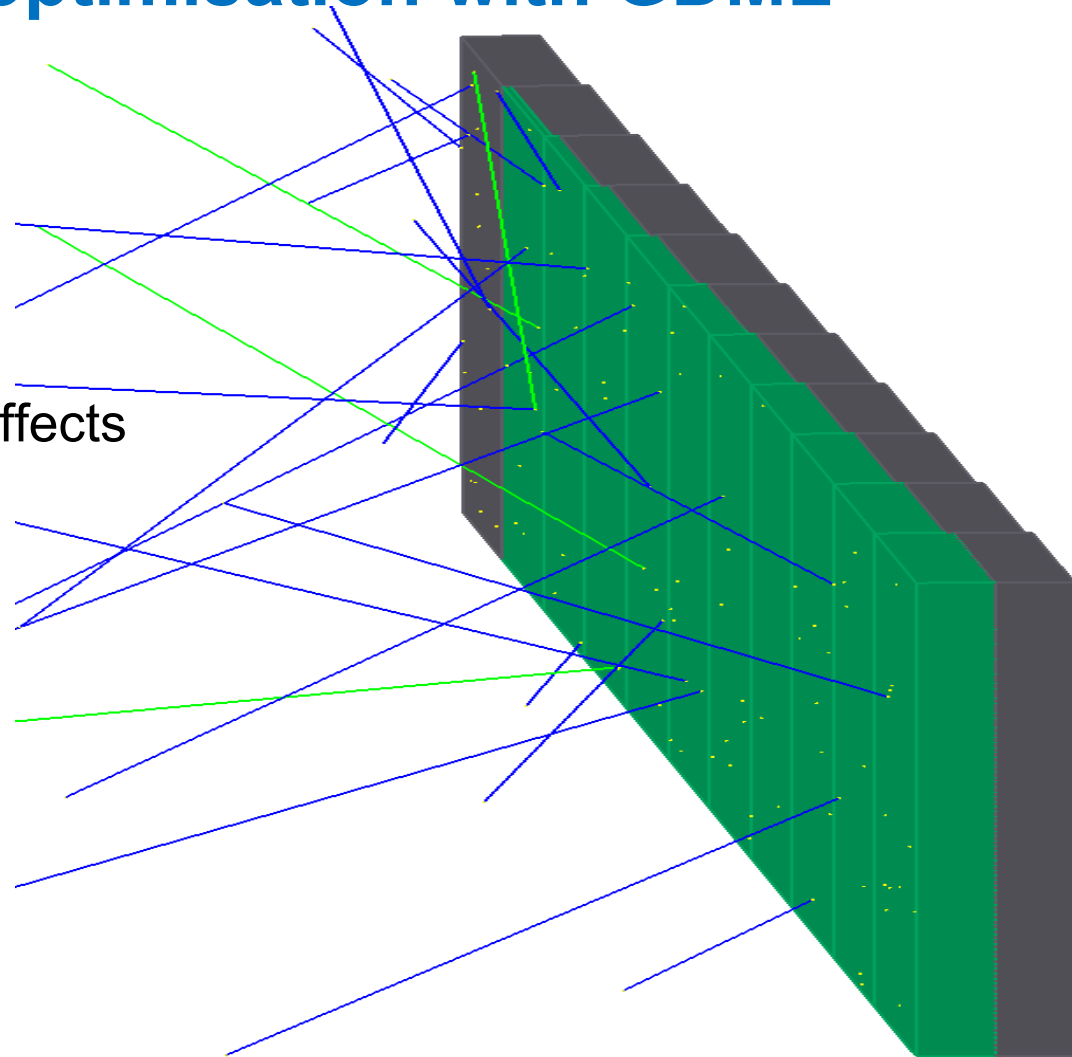


*Anton Fetzer, Marius Anger,
Philipp Oleynik and Jaan Praks*

Multilayer Shielding optimisation with GDML

Shielding Geometry

- Planar shielding tiles
- Implemented in GDML
- 10 x 10m to reduce edge effects
- Silicon detector (0.5mm)
- Cosine angular distributed particles generated on surface of shield



Shielding Geometry

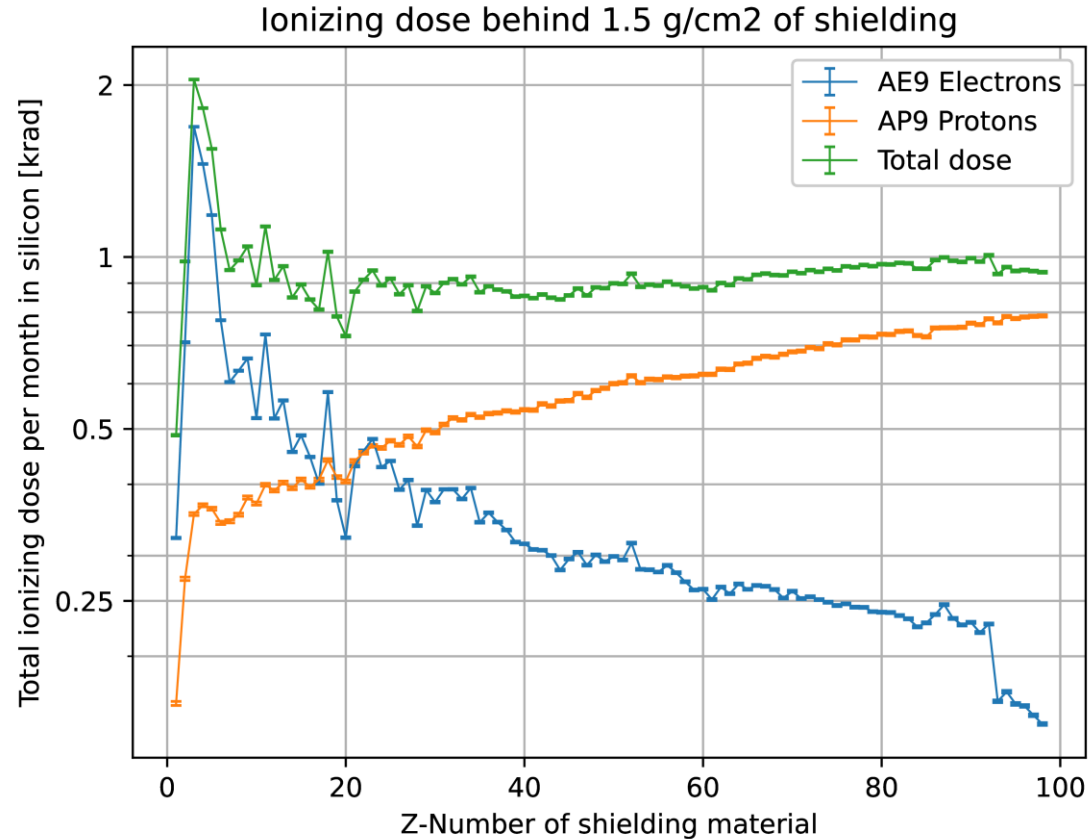
GDML code

```
<volume name="ShieldingCurves" >
  <materialref ref="G4_Galactic" />
  <solidref ref="WorldBox" />
  ...<loop for="x" from="0" to="100" step="1">
    <!-- Beam starts at z=0 and goes into -z direction -->
    <physvol>
      <volumeref ref="AlVol[x]" />
      <position name="AlPos[x]" x="Len*x-Len*50" y="0" z="- Alt*x/2" /> <!-- Al shield in front of the Si detector -->
    </physvol>
    <physvol>
      <volumeref ref="SiVol[x]" />
      <position name="SiPos[x]" x="Len*x-Len*50" y="0" z="- SiT/2 - Alt*x - 0.0000001" /> <!-- Si detector behind the shield -->
    </physvol>
  </loop>
</volume>
```



Shielding Performance of Chemical Elements

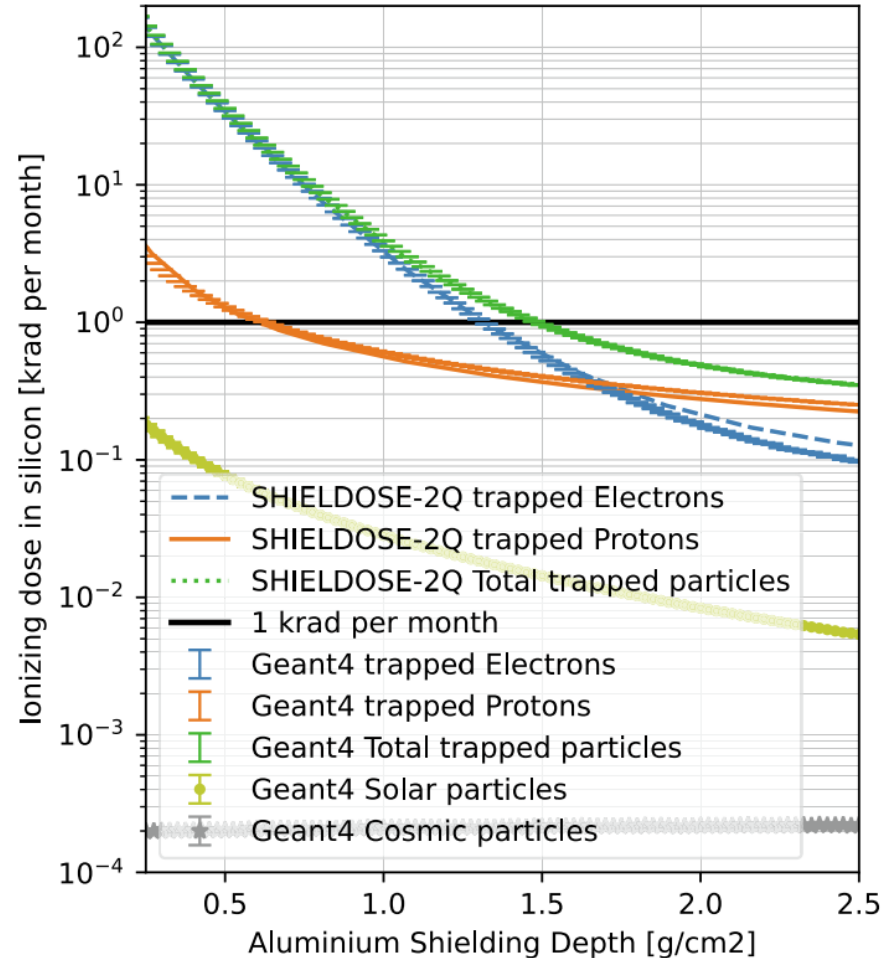
- 98 tiles consisting of the first 98 chemical elements
- Fixed shielding mass
- Hydrogen exceptional shielding material
- Low-Z good against protons
- High-Z good against electrons



Validation: GRAS vs SHIELDOSE

- 100 aluminium shielding tiles
- Placed next to each other in one GDML file
- Varying shielding thickness from 0.25 to 2.5g/cm²
- Comparison with SHIELDOSE on SPENVIS

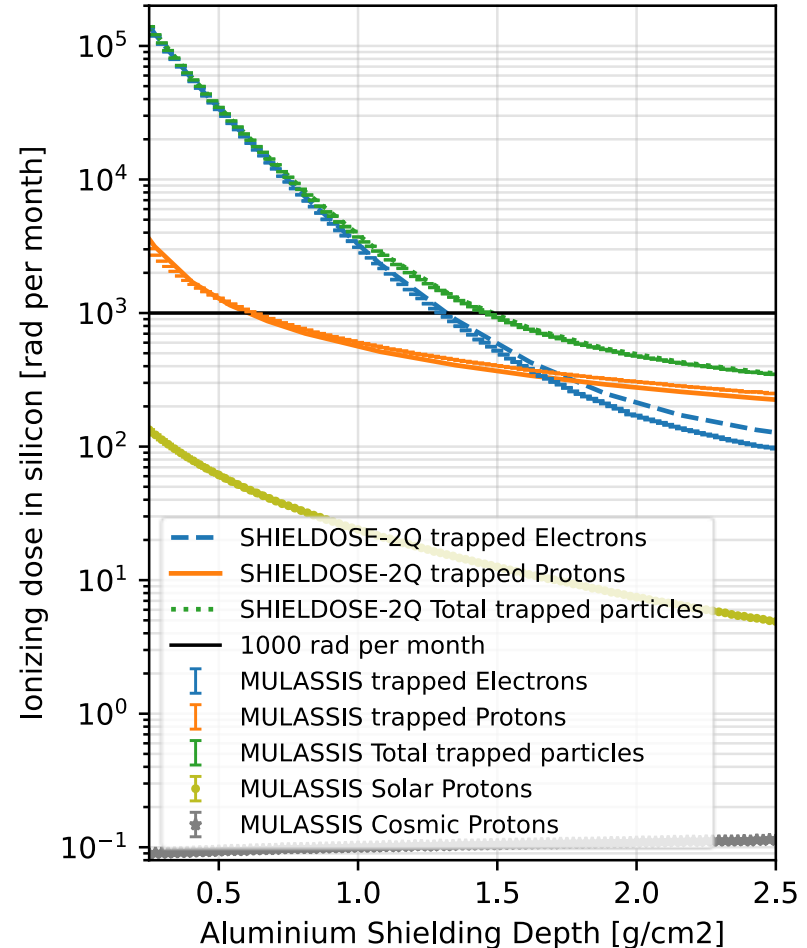
Comparison between Geant4 and SHIELDOSE-2Q



Validation: MULASSIS vs SHIELDOSE

- 100 aluminium shielding tiles
- **Procedurally generated independent simulation macros**
- Varying shielding thickness from 0.25 to 2.5g/cm²
- Comparison with SHIELDOSE on SPENVIS

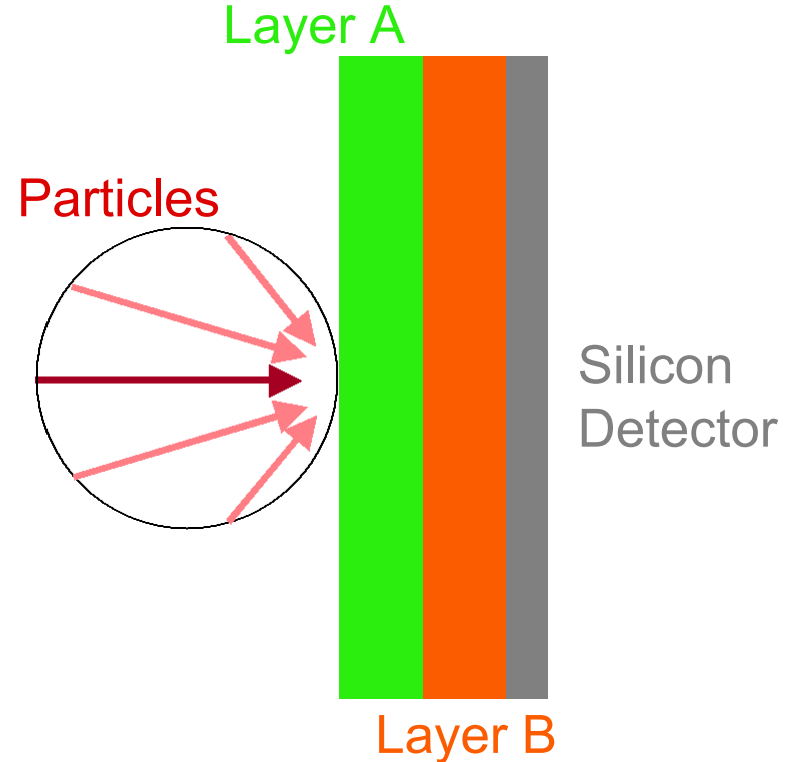
Comparison between MULASSIS and SHIELDOSE-2Q



Multilayer Optimisation with GRAS

2-Layer Permutations

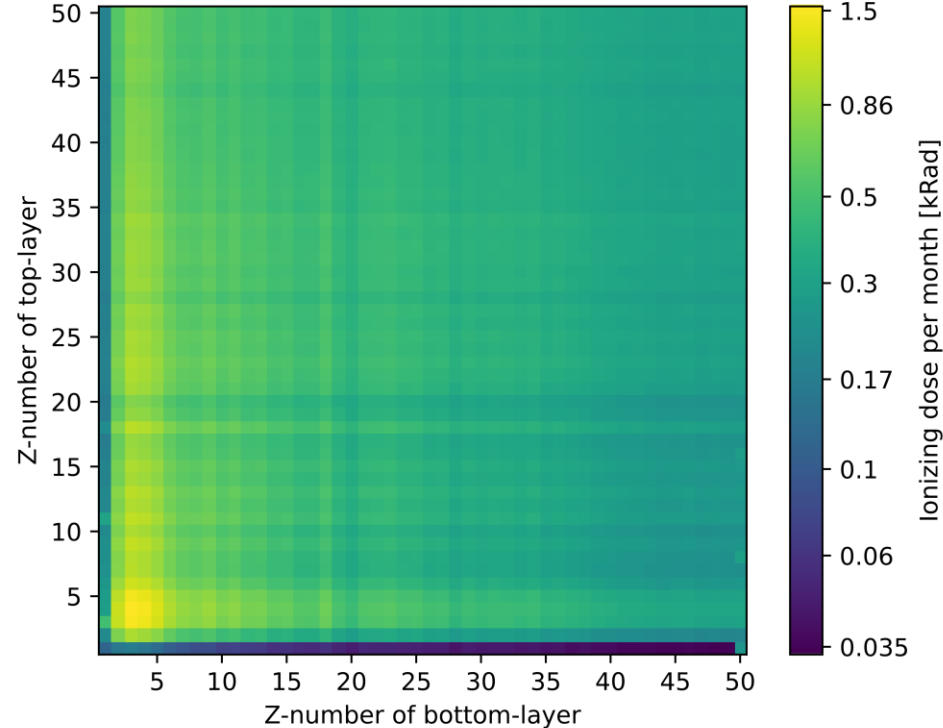
- First 50 chemical elements
- 2 layers of equal mass
→ 2500 combinations
- Placed next to each other using GDML for-loops
- Irradiated by the same beam
- Detector layer to record shielded ionising dose



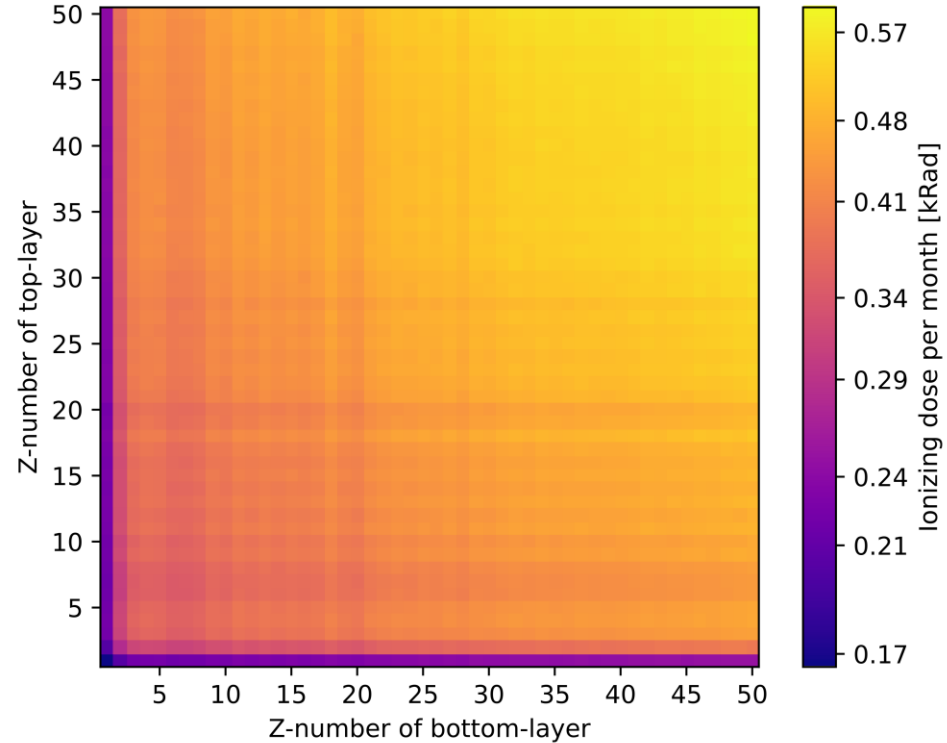
Multilayer Optimisation with GRAS

2-Layer Permutations

Electron dose for two layer shielding



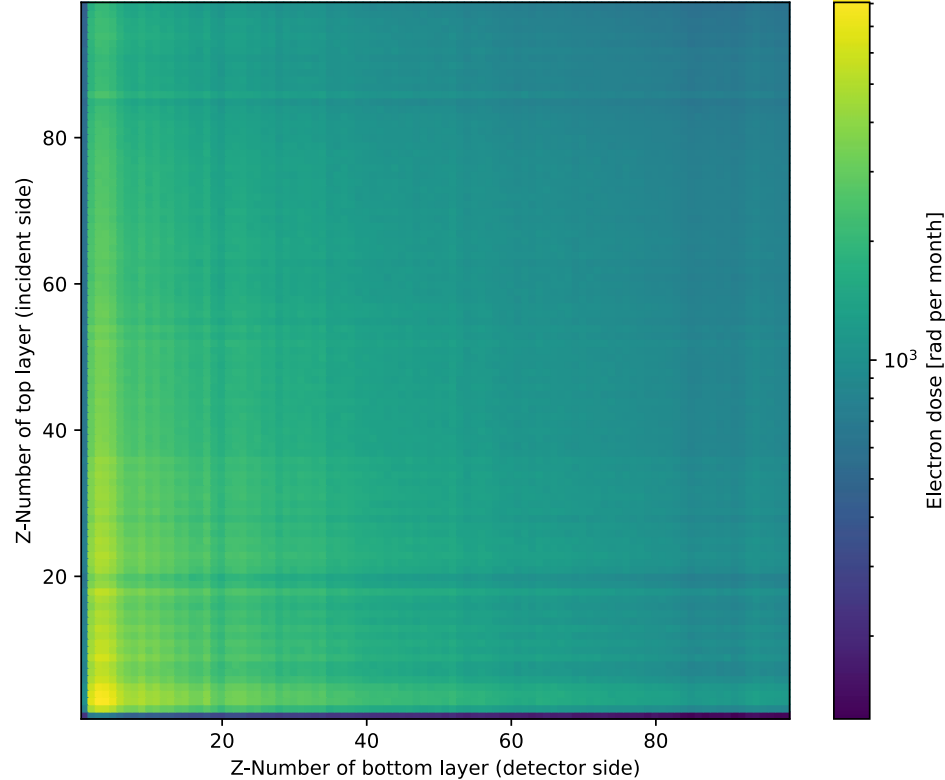
Proton dose for two layer shielding



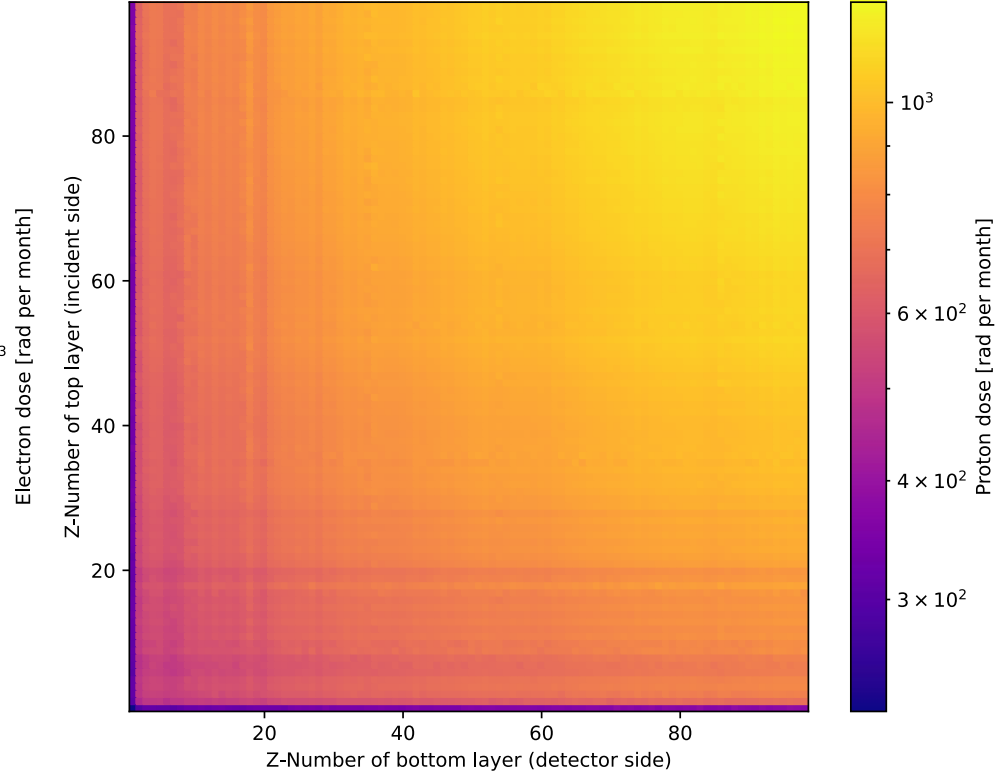
Multilayer Optimisation with MULASSIS

2-Layer Permutations

Electron dose behind two-layer shielding



Proton dose behind two-layer shielding



GRAS vs MULASSIS

GRAS

Geant4 Radiation Analysis for Space

All geometries in one GDML file

→ Simple simulation setup

Each thread simulates the whole geometry

→ Large geometries slow down simulation

MULASSIS

MUlti-LAYer Shielding Simulation Software

Geometry definition spread over many macro config files

→ Complex setup with many files

Each layer stack is a fully independent simulation

→ Cost scales strictly linear with number of geometries



Aalto University
School of Electrical
Engineering



Space Environment

European Space Agency

GRAS vs MULASSIS

GRAS

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Valid excuse in 2024.
Not in 2026

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Easy with coding agents



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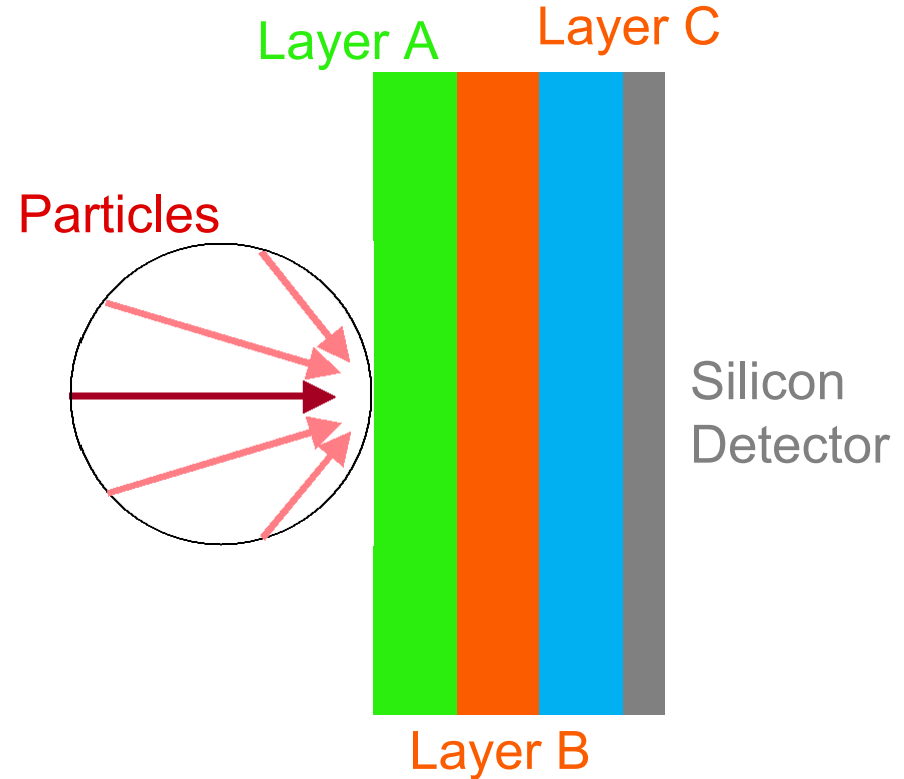
Easy with coding agents



Multilayer Optimisation

3-Layer Permutations

- Adding one more layer multiplies the number of permutations with the number of materials
- Number of materials must be reduced to be able to compute all permutations
 - 12 common shielding materials



Multilayer Optimisation with GRAS

3-Layer Permutations

The three-layer shielding material combinations, which resulted in the lowest and highest TID of a total of 1728 simulated combinations of twelve different materials against the trapped electron and proton spectra. The aluminium alloy Al-7075 was included as a reference. Each of the layers has a depth of 0.5g/cm² for a total shielding depth of 1.5g/cm². The combinations are sorted and ranked according to their total dose shielding performance and presented with their statistical error. The full dataset with all 1728 combinations is publicly available on Zenodo ([Fetzer, 2023d](#)).

Rank	Shielding Layers			Ionising dose [krad]		
	A	B	C	Electrons	Protons	Total Dose
1	PE	PE	Pb	0.135 ± 0.004	0.3703 ± 0.0015	0.506 ± 0.004
2	PE	PE	Ta	0.145 ± 0.004	0.3654 ± 0.0014	0.511 ± 0.004
3	PE	PE	W	0.15 ± 0.004	0.3679 ± 0.0015	0.518 ± 0.004
4	PE	Kevlar	Pb	0.156 ± 0.004	0.3857 ± 0.0015	0.541 ± 0.004
5	Kevlar	PE	Pb	0.157 ± 0.004	0.3859 ± 0.0015	0.542 ± 0.004
...
1482	Al-7075	Al-7075	Al-7075	0.53 ± 0.007	0.4091 ± 0.0014	0.939 ± 0.007
...
1724	Teflon	Teflon	Carbon fibre	0.728 ± 0.007	0.3537 ± 0.0015	1.082 ± 0.008
1725	Al-7075	Teflon	Teflon	0.711 ± 0.008	0.3804 ± 0.0015	1.092 ± 0.008
1726	Ti_6AL_4V	Teflon	Teflon	0.711 ± 0.008	0.3885 ± 0.0015	1.099 ± 0.008
1727	Al-6061	Teflon	Teflon	0.726 ± 0.008	0.3792 ± 0.0014	1.105 ± 0.008
1728	Teflon	Teflon	Teflon	0.744 ± 0.007	0.3688 ± 0.0015	1.113 ± 0.008



Multilayer Optimisation with GRAS

4-Layer Permutations

The four-layer shielding material combinations which resulted in the lowest and highest TID of a total of 1296 simulated combinations of six different materials against the trapped electron and proton spectra. The aluminium alloy Al-7075 was included as a reference. Each of the layers has a depth of 0.375g/cm^2 for a total shielding depth of 1.5g/cm^2 . The combinations are sorted and ranked according to their total dose shielding performance and presented with their statistical error. The full dataset with all 1296 combinations is publicly available on Zenodo ([Fetzer, 2023c](#)).

Rank	Shielding Layers				Ionising dose [krad]		
	A	B	C	D	Electrons	Protons	Total Dose
1	PE	PE	PE	W	0.1639 ± 0.0027	0.3465 ± 0.0013	0.5103 ± 0.003
2	PE	PE	Kevlar	W	0.1805 ± 0.0029	0.3576 ± 0.0014	0.5381 ± 0.0032
3	PE	Kevlar	PE	W	0.1816 ± 0.0029	0.3581 ± 0.0013	0.5396 ± 0.0031
4	PE	PE	W	W	0.1257 ± 0.0023	0.4143 ± 0.0014	0.54 ± 0.0028
5	PE	PE	FR4	W	0.1733 ± 0.0028	0.3701 ± 0.0014	0.5434 ± 0.0031
...
1265	Al-7075	Al-7075	Al-7075	Al-7075	0.525 ± 0.004	0.4078 ± 0.001	0.933 ± 0.005
...
1292	Al-7075	Al-7075	Kevlar	Kevlar	0.613 ± 0.005	0.3573 ± 0.001	0.97 ± 0.005
1293	W	Al-7075	Al-7075	Al-7075	0.518 ± 0.004	0.4515 ± 0.002	0.97 ± 0.005
1294	Al-7075	Kevlar	Kevlar	Kevlar	0.633 ± 0.005	0.3411 ± 0.001	0.974 ± 0.005
1295	Steel	Al-7075	Kevlar	Kevlar	0.611 ± 0.005	0.3665 ± 0.001	0.978 ± 0.005
1296	Steel	Al-7075	Al-7075	Kevlar	0.595 ± 0.005	0.3888 ± 0.001	0.984 ± 0.005



Multilayer Optimisation with GRAS

5-Layer Permutations

The five-layer shielding material combinations that resulted in the lowest and highest TID of 1024 simulated combinations of four different materials against the trapped electron and proton spectra. The aluminium alloy Al-7075 was included as a reference. Each of the layers has a depth of $0.3\text{g}/\text{cm}^2$ for a total shielding depth of $1.5\text{g}/\text{cm}^2$. The combinations are sorted and ranked according to their total dose shielding performance and presented with their statistical error. The full dataset with all 1024 combinations is publicly available on Zenodo ([Fetzer, 2023b](#)).

Rank	Shielding Layers					Ionising dose [krad]		
	A	B	C	D	E	Electrons	Protons	Total Dose
1	PE	PE	PE	PE	W	0.1809 ± 0.0017	0.3341 ± 0.0014	0.5149 ± 0.0022
2	PE	PE	PE	W	W	0.1362 ± 0.0015	0.3857 ± 0.0014	0.522 ± 0.0021
3	PE	PE	W	PE	W	0.1454 ± 0.0016	0.3811 ± 0.0017	0.5265 ± 0.0023
4	PE	PE	PE	FR4	W	0.1863 ± 0.0018	0.3519 ± 0.0013	0.5381 ± 0.0022
5	PE	PE	FR4	PE	W	0.1879 ± 0.0018	0.3513 ± 0.0012	0.5392 ± 0.0021
...
1012	Al-7075	Al-7075	Al-7075	Al-7075	Al-7075	0.5246 ± 0.0028	0.4089 ± 0.001	0.934 ± 0.0032
...
1020	W	Al-7075	Al-7075	Al-7075	FR4	0.5302 ± 0.0026	0.4278 ± 0.001	0.958 ± 0.003
1021	W	W	W	W	W	0.2501 ± 0.0018	0.71 ± 0.002	0.96 ± 0.0025
1022	W	FR4	Al-7075	Al-7075	Al-7075	0.527 ± 0.0027	0.4333 ± 0.002	0.96 ± 0.0031
1023	W	Al-7075	Al-7075	FR4	Al-7075	0.5288 ± 0.0027	0.432 ± 0.002	0.961 ± 0.0031
1024	W	Al-7075	Al-7075	Al-7075	Al-7075	0.5467 ± 0.0028	0.4413 ± 0.001	0.988 ± 0.0031



Multilayer Optimisation with MULASSIS

5-Layer Permutations

Rank	Shielding Layers					Ionising dose [krad]		
	A	B	C	D	E	Electrons	Protons	Total Dose
1	PE	PE	PE	PE	W	0.1826 ± 0.0004	0.3342 ± 0.0002	0.5167 ± 0.0005
2	PE	PE	PE	W	W	0.1342 ± 0.0004	0.3860 ± 0.0002	0.5202 ± 0.0005
3	PE	PE	PE	W	PE	0.1976 ± 0.0004	0.3246 ± 0.0002	0.5221 ± 0.0005
4	PE	PE	W	PE	W	0.1426 ± 0.0005	0.3814 ± 0.0002	0.5240 ± 0.0005
5	PE	PE	W	W	PE	0.1600 ± 0.0004	0.3688 ± 0.0002	0.5288 ± 0.0005
...
980	Al	Al	Al	Al	Al	0.5032 ± 0.0131	0.4010 ± 0.0011	0.9041 ± 0.0131
...
1020	W	Al	Kevlar	Kevlar	Kevlar	0.5923 ± 0.0125	0.3746 ± 0.0012	0.9668 ± 0.0126
1021	W	Al	Al	Kevlar	Al	0.5587 ± 0.0126	0.4122 ± 0.0011	0.9708 ± 0.0127
1022	W	Al	Al	Kevlar	Kevlar	0.5917 ± 0.0126	0.3896 ± 0.0011	0.9813 ± 0.0126
1023	W	Al	Al	Al	Kevlar	0.5845 ± 0.0125	0.4076 ± 0.0011	0.9921 ± 0.0126
1024	W	Al	Al	Al	Al	0.5647 ± 0.0127	0.4360 ± 0.0011	1.0008 ± 0.0128

1024 ordered 5-layer stacks of PE / W / Kevlar / Al, 0.3 g/cm² per layer (1.5 g/cm² total), 0.5 mm Si detector, OldGTO orbit; sigma-race converged to 1%. Dose in krad/month ± 1σ.

Multilayer Optimisation

2-Layer Mass Allocation

- After suitable materials are identified:
→ Vary mass allocation between layers

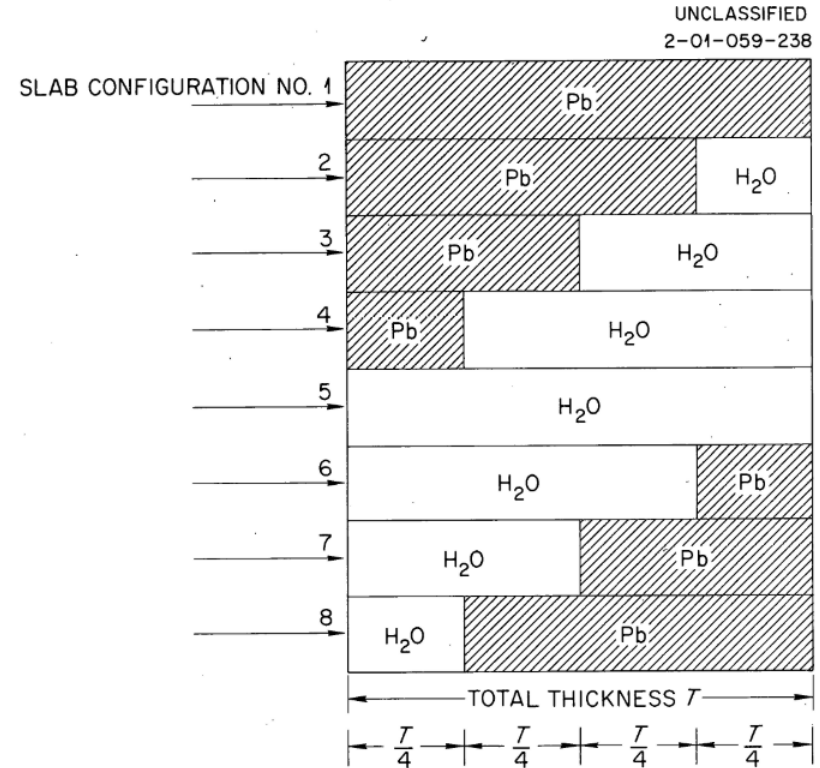
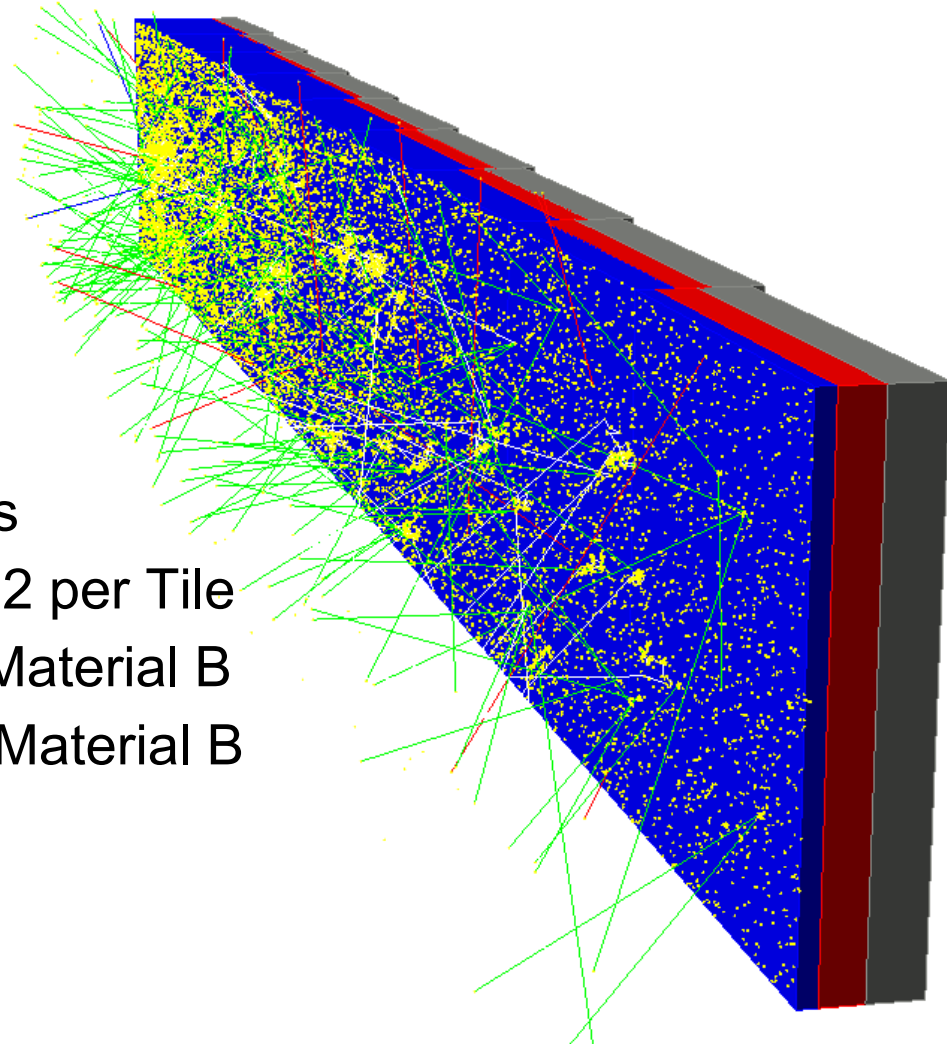


Fig. 1. Stratified Slab Configurations.

Multilayer Optimisation with GRAS

2-Layer Mass Allocation

- After suitable materials are identified:
 - Vary mass allocation between layers
- 2-Layer shielding + detector tiles
- Shielding mass fixed at 1.5g/cm² per Tile
- 1st Tile: 10% Material A + 90% Material B
- 2nd Tile: 20% Material A + 90% Material B
- ...

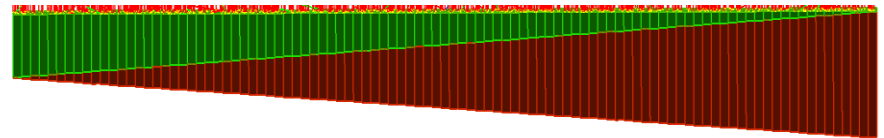
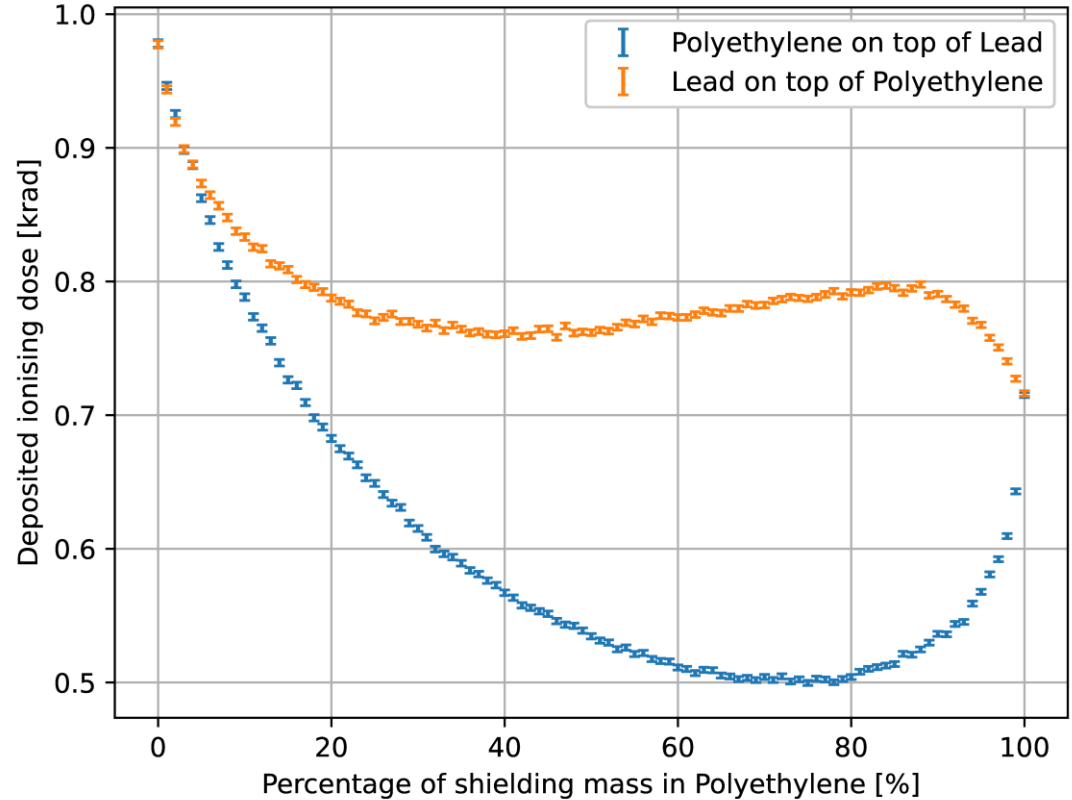


Multilayer Optimisation with GRAS

2-Layer Mass Allocation

- Shielded dose depends on order of materials
- Low-Z on top of high-Z best on GTO
- Example: PE on Pb
- TID reduction:
 - 45% less than Pb
 - 30% less than PE

Total dose deposited by trapped particles in 0.5 mm Si behind 1.5 g/cm² of Polyethylene-Lead shielding



GRAS vs MULASSIS

GRAS

Geant4 Radiation Analysis for Space

Whole geometry irradiated by the same particle source

- Simple simulation setup
- All geometries receive the same number of simulated primaries

MULASSIS

MULTi-LAYer Shielding Simulation Software

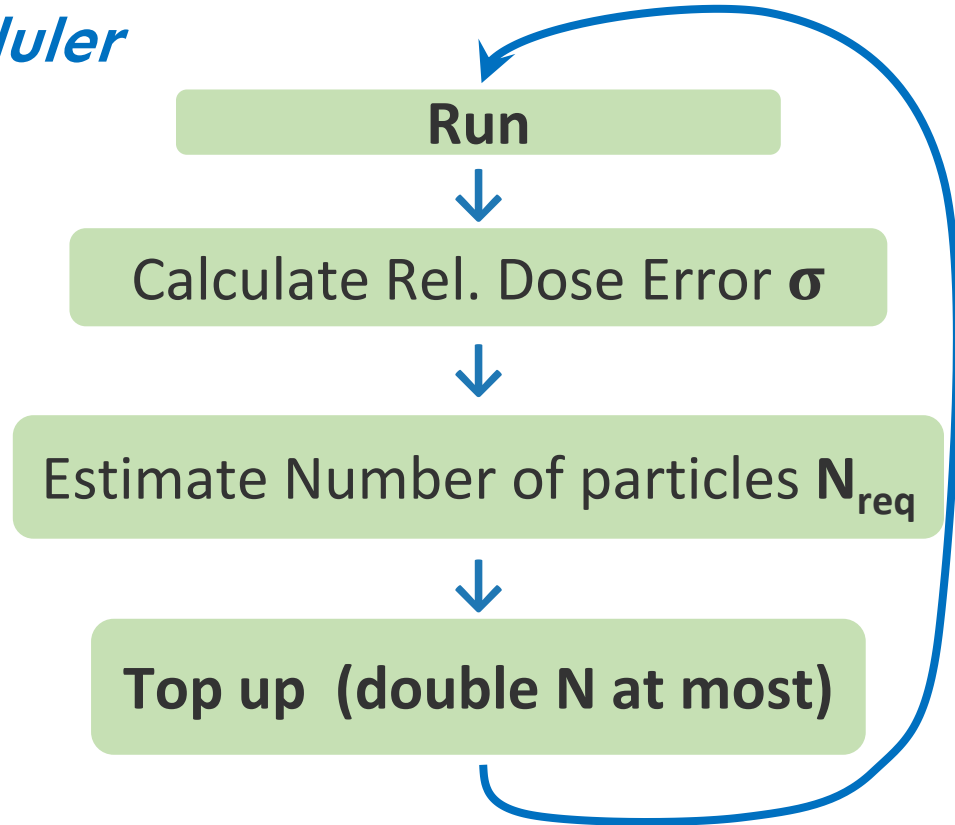
Each layer stack has its own particle source

- Complex simulation setup
- Number of simulated primaries can be adjusted per stack!

Multilayer Optimisation with MULASSIS

Uniform Adaptive Run Scheduler

- Each shielding tile is an independent simulation
 - Uncertainty $\sim \sqrt{N}$
 - MULASSIS does not allow to set a target uncertainty
- Split run into time limited chunks

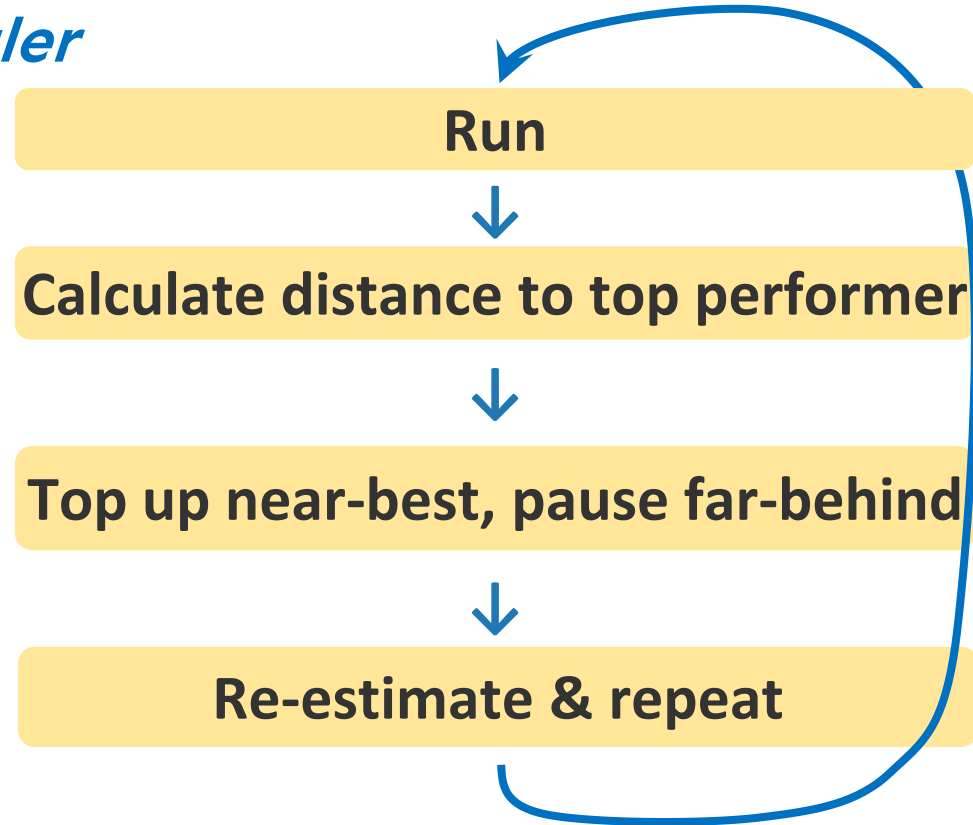


$$N_{\text{target}} = N_{\text{have}} \cdot \left(\frac{\sigma_{\text{now}}}{\sigma_{\text{target}}} \right)^2$$

Multilayer Optimisation with MULASSIS

Sigma Adaptive Run Scheduler

- Calculate the distance to the top performing configuration in terms of standard deviations
 σ_s = Sigma distance
- Top up inversely proportional to σ_s
- Tiles further than $2 \sigma_s$ receive no additional particles

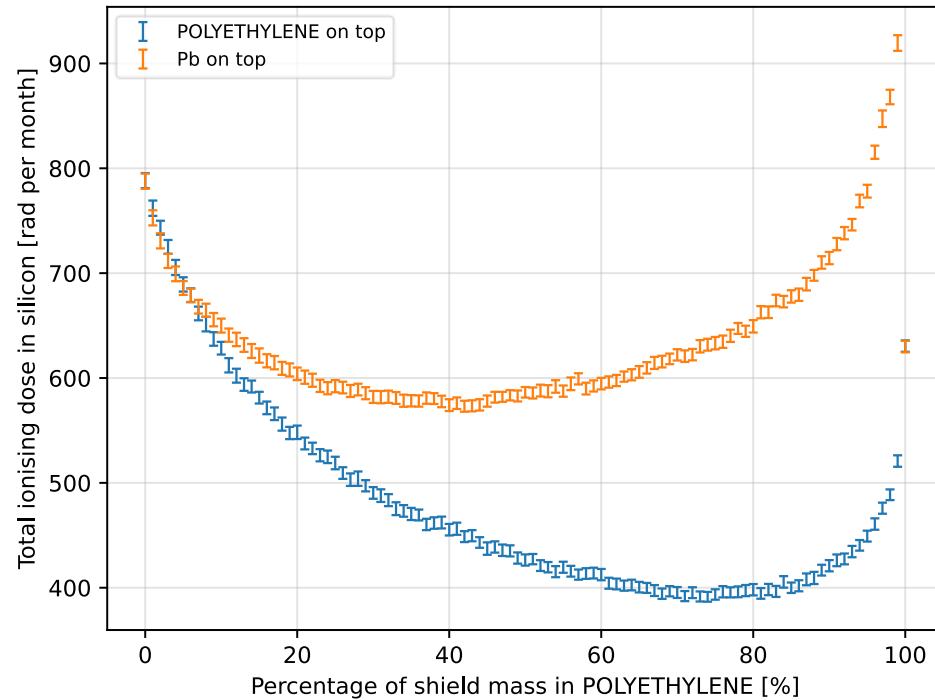


$$\sigma_s = (D_s - D_{\text{best}}) / \sqrt{(\text{err}_s^2 + \text{err}_{\text{best}}^2)}$$

Multilayer Optimisation with MULASSIS

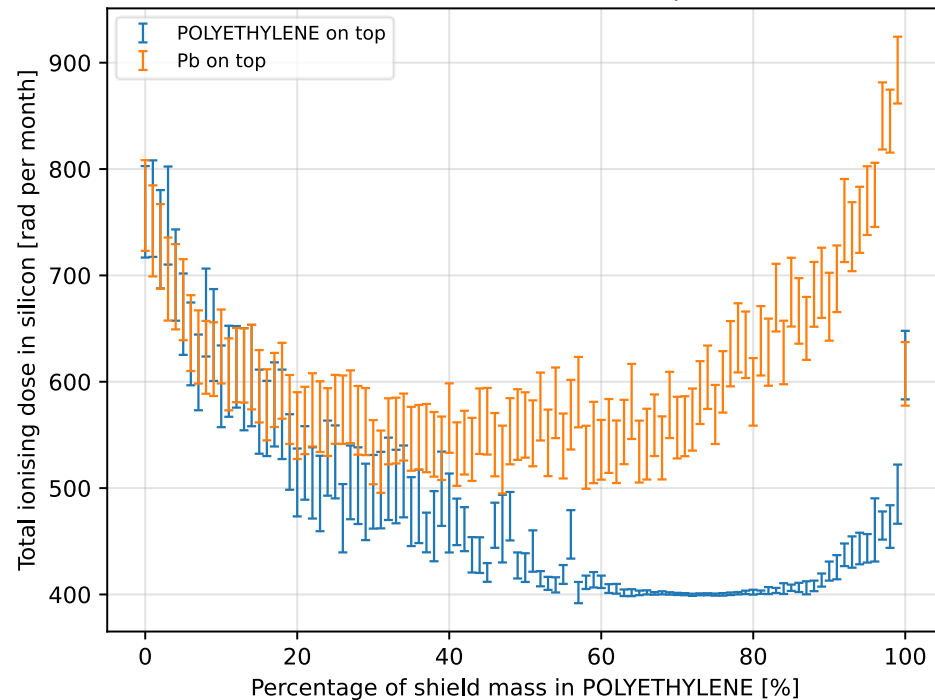
Dynamic Schedulers

Minimum dose 391.4 ± 4.7 rad per month
at 74% POLYETHYLENE on top of Pb



Dynamic Uniform Scheduler 1% Target Error

Minimum dose 399.7 ± 1 rad per month
at 72% POLYETHYLENE on top of Pb



Dynamic Sigma Rank Scheduler 0.1% Target Error

Multilayer Optimisation

3-Layer Ternary Mass Allocation

- Shielding mass fixed at 1.5g/cm² per Tile
- Top corner: 100% Material 1
- Lower right: 100% Material 2
- Lower left: 100% Material 3
- Tiles in the middle mixed proportional to their coordinates

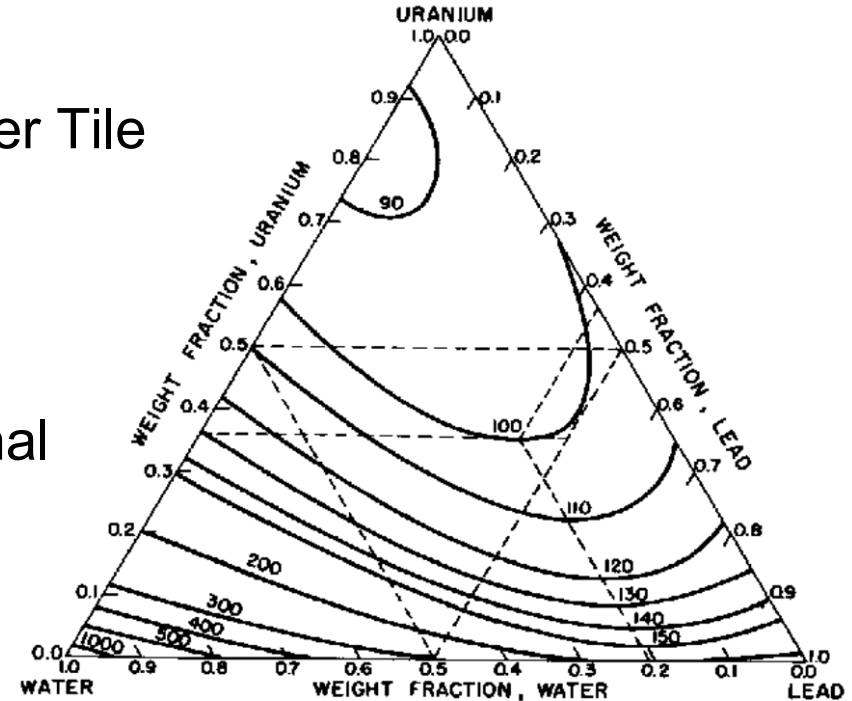
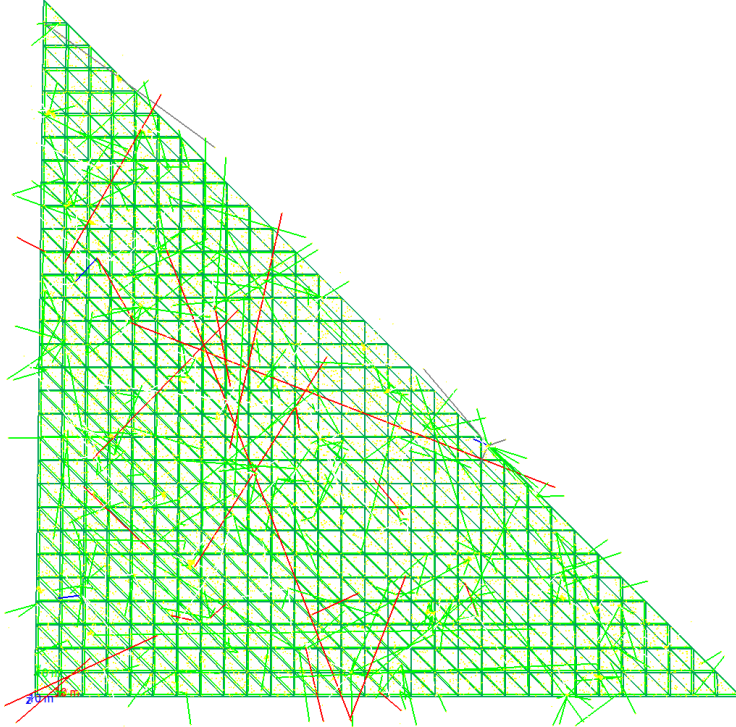


Fig. 5. Weight variation of uranium-lead-water shield.

A. F. Rohach, "Weight Optimization of Gamma-Ray Shields Using Layered Media and Spherical Geometry," *Nuclear Science and Engineering*, vol. 27, no. 2, pp. 464–466, Feb. **1967**, doi: 10.13182/nse67-a18285.

Multilayer Optimisation with GRAS

3-Layer Ternary Mass Allocation



Geometry implemented in GDML

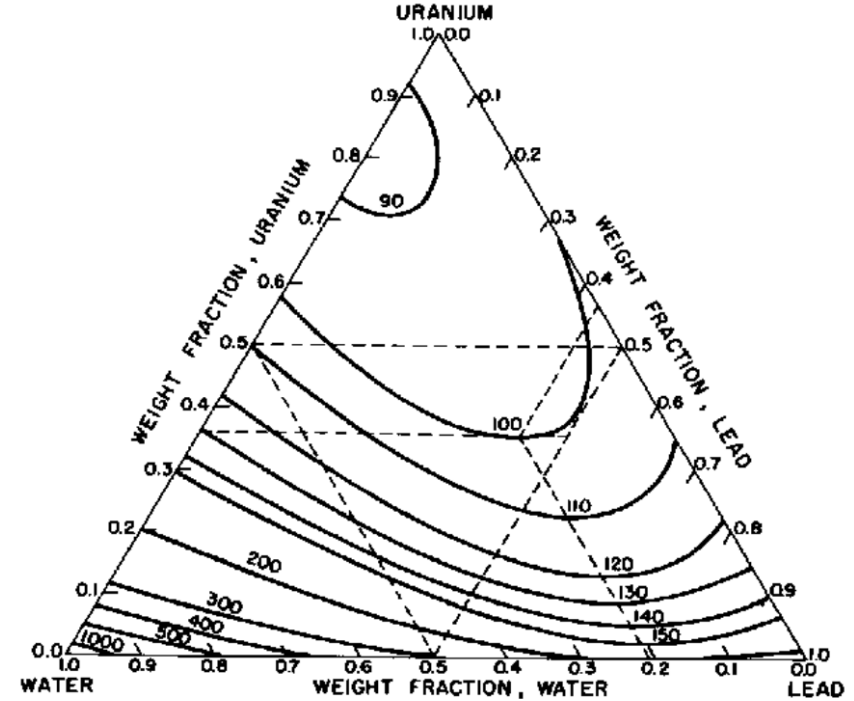


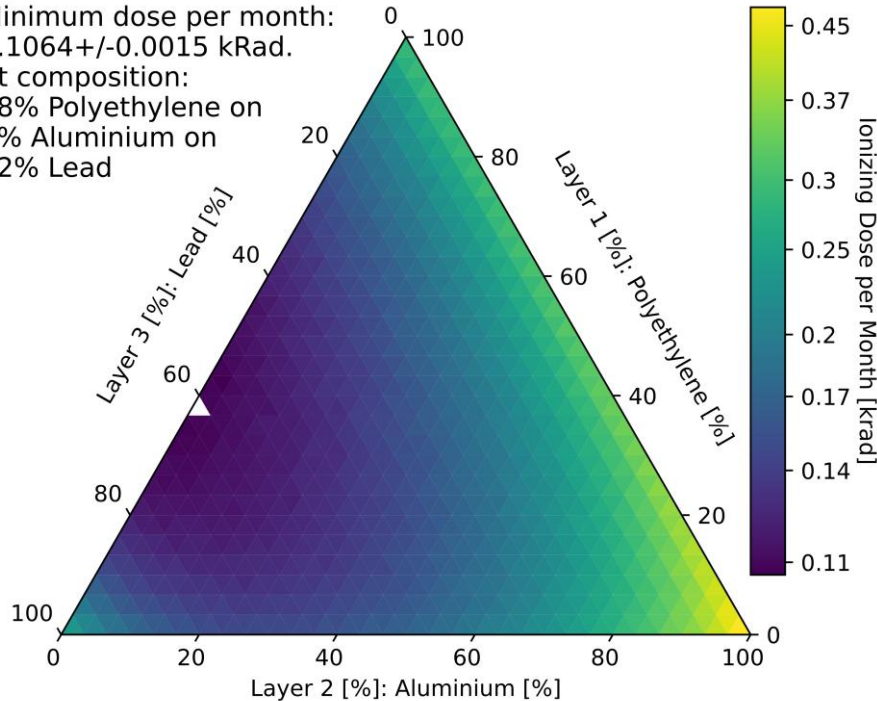
Fig. 5. Weight variation of uranium-lead-water shield.

Multilayer Optimisation with GRAS

3-Layer Ternary Mass Allocation

Minimum dose per month:
0.1064 +/- 0.0015 kRad.

At composition:
38% Polyethylene on
0% Aluminium on
62% Lead



TID due to electrons on GTO

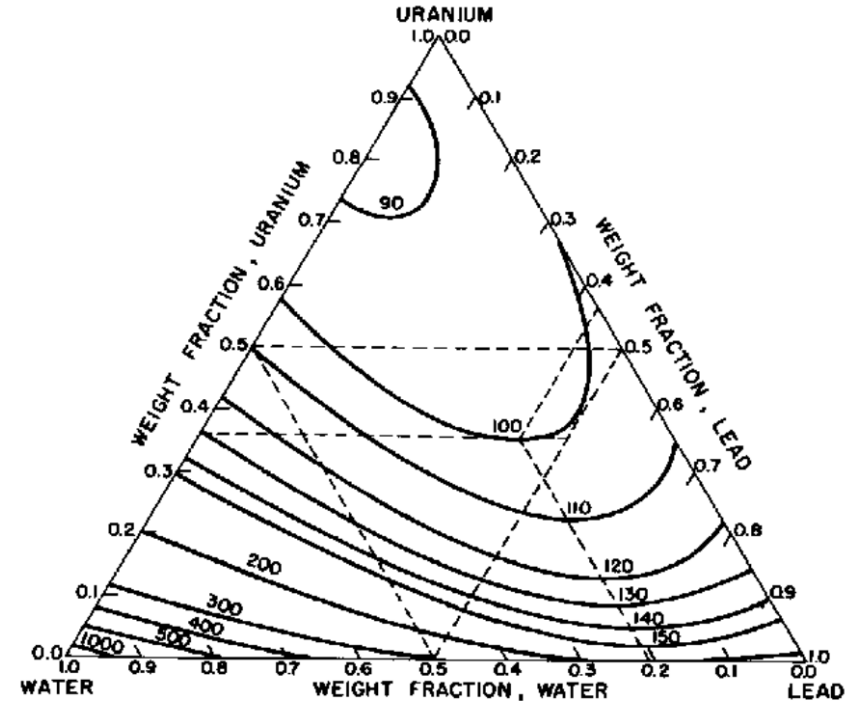
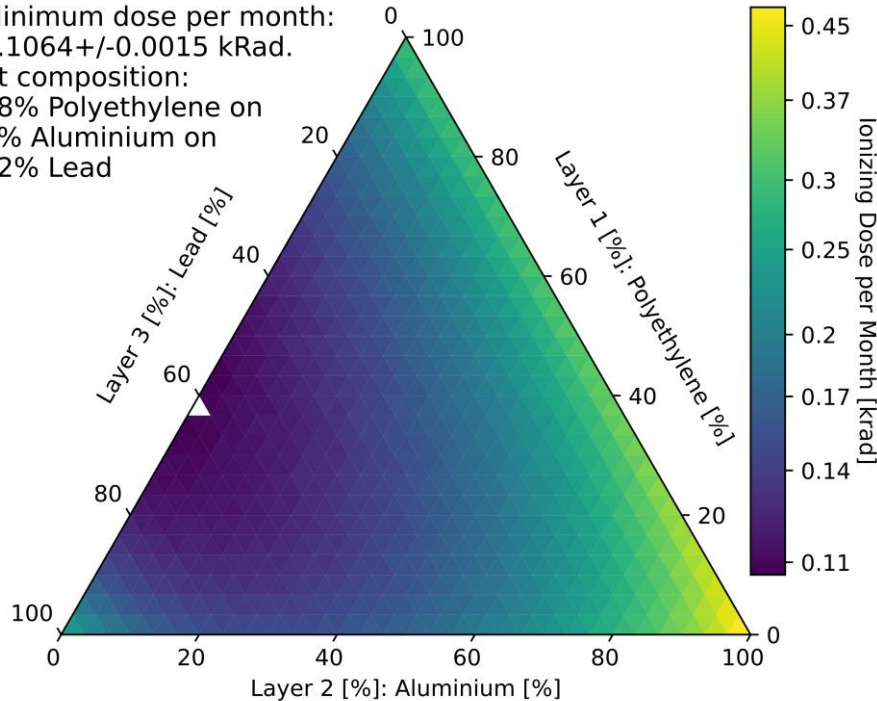


Fig. 5. Weight variation of uranium-lead-water shield.

Multilayer Optimisation with GRAS

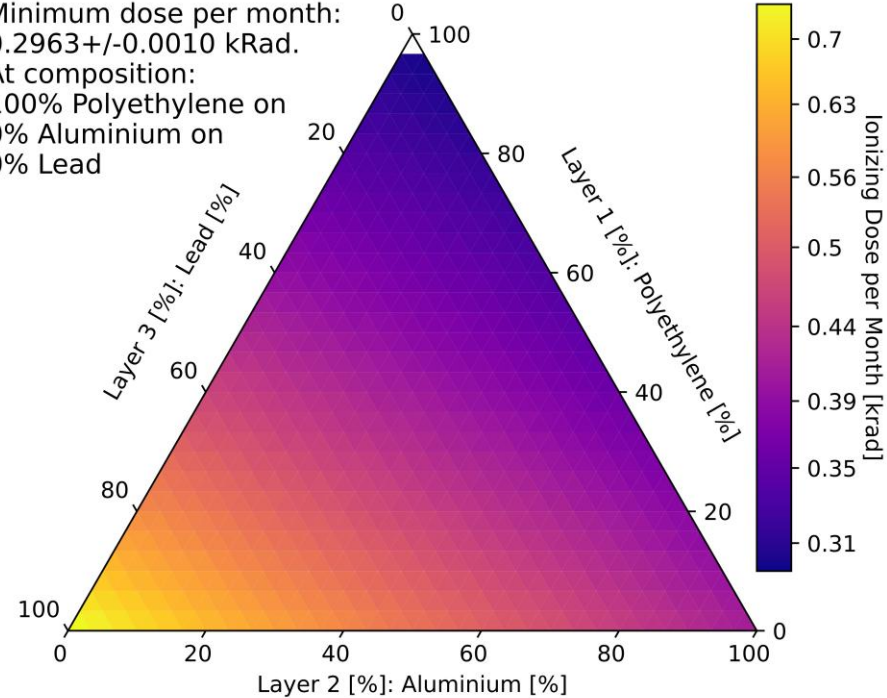
3-Layer Ternary Mass Allocation

Minimum dose per month:
0.1064 +/- 0.0015 kRad.
At composition:
38% Polyethylene on
0% Aluminium on
62% Lead



TID due to electrons on GTO

Minimum dose per month:
0.2963 +/- 0.0010 kRad.
At composition:
100% Polyethylene on
0% Aluminium on
0% Lead

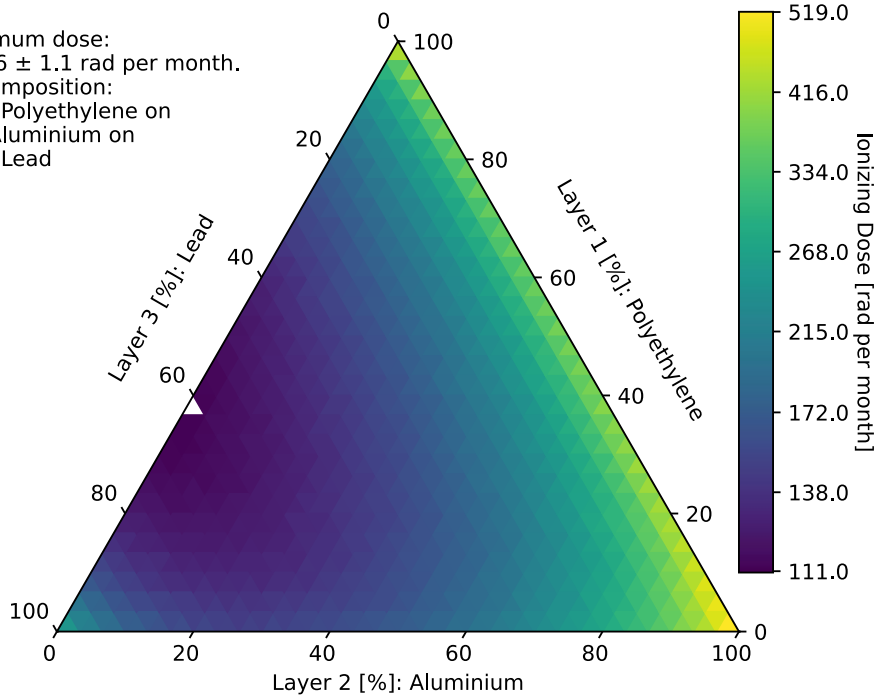


TID due to protons on GTO

Multilayer Optimisation with MULASSIS

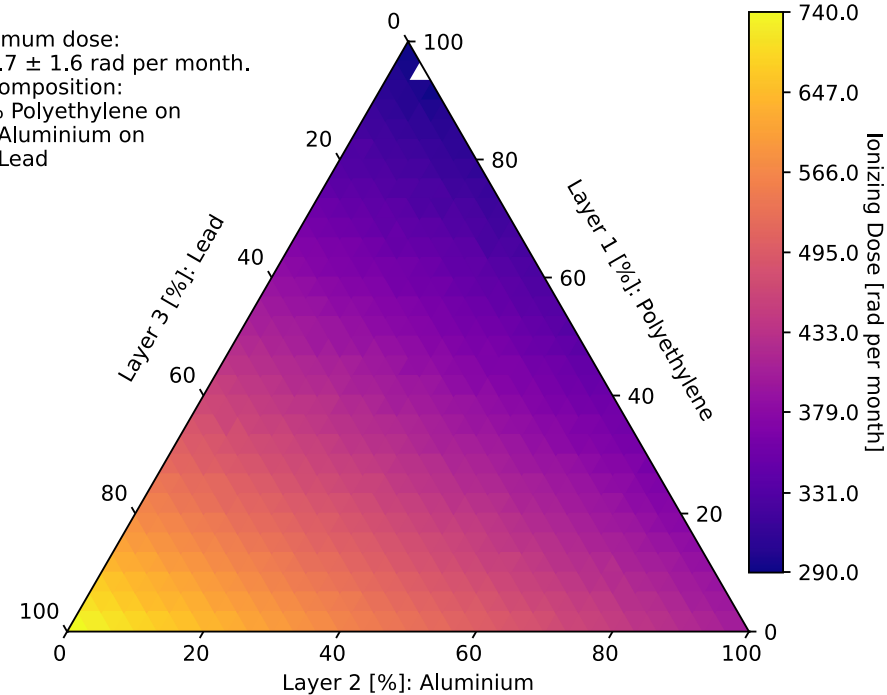
3-Layer Ternary Mass Allocation

Minimum dose:
 110.6 ± 1.1 rad per month.
At composition:
38% Polyethylene on
0% Aluminium on
62% Lead



TID due to electrons on GTO

Minimum dose:
 289.7 ± 1.6 rad per month.
At composition:
97% Polyethylene on
3% Aluminium on
0% Lead

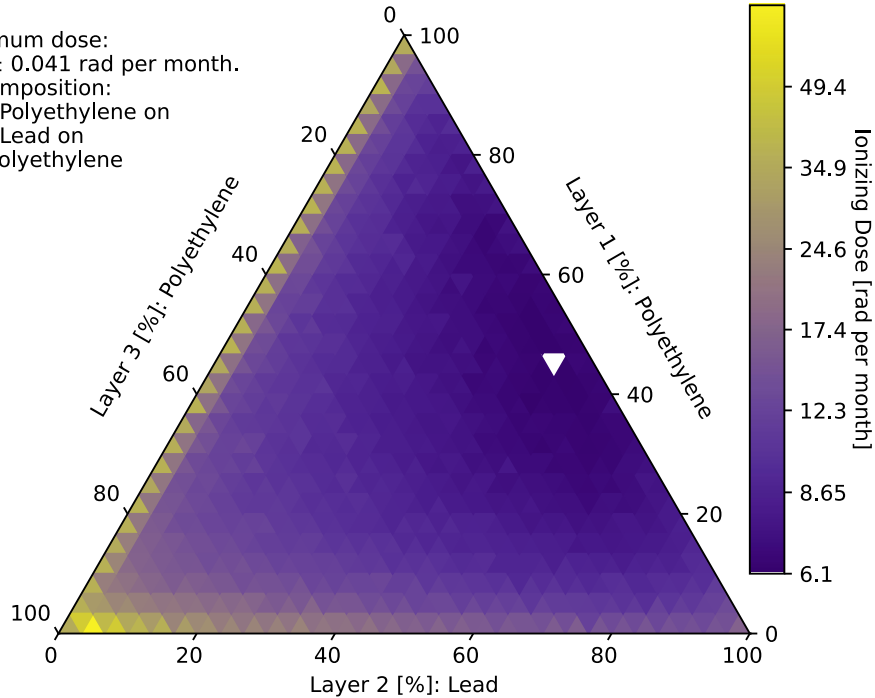


TID due to protons on GTO

Multilayer Optimisation with MULASSIS

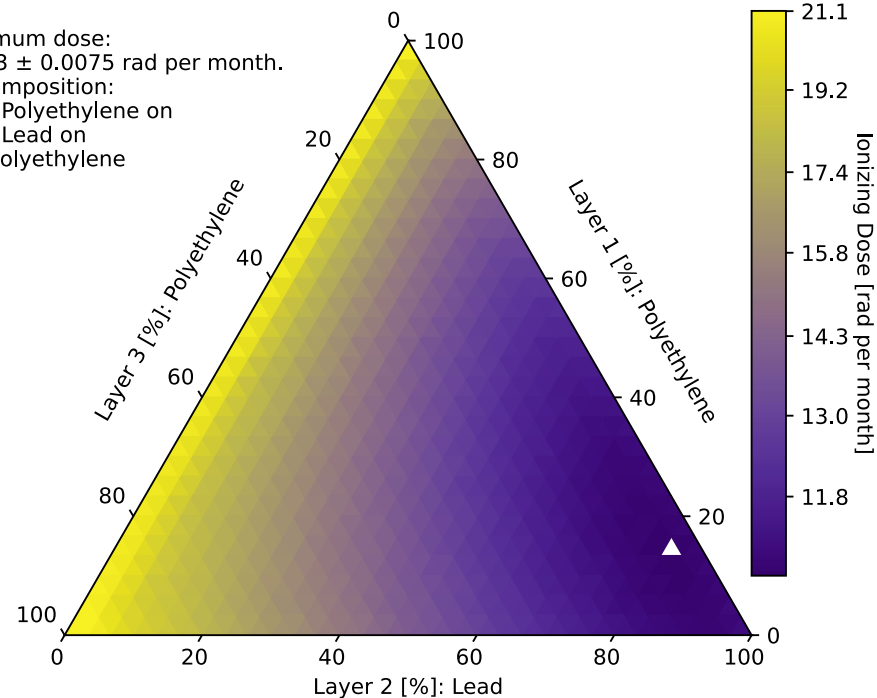
3-Layer Ternary Mass Allocation

Minimum dose:
 6.1 ± 0.041 rad per month.
At composition:
46% Polyethylene on
49% Lead on
5% Polyethylene



TID on GEO behind 1.5g/cm²

Minimum dose:
 10.73 ± 0.0075 rad per month.
At composition:
14% Polyethylene on
83% Lead on
3% Polyethylene

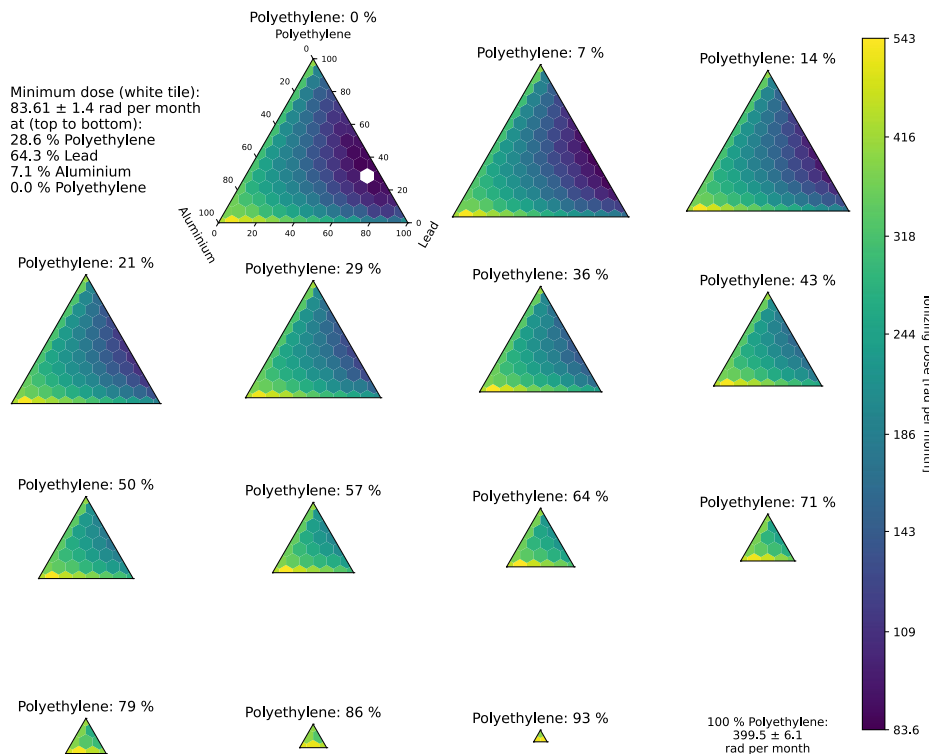


TID on SSO behind 0.5g/cm²

Multilayer Optimisation with MULASSIS

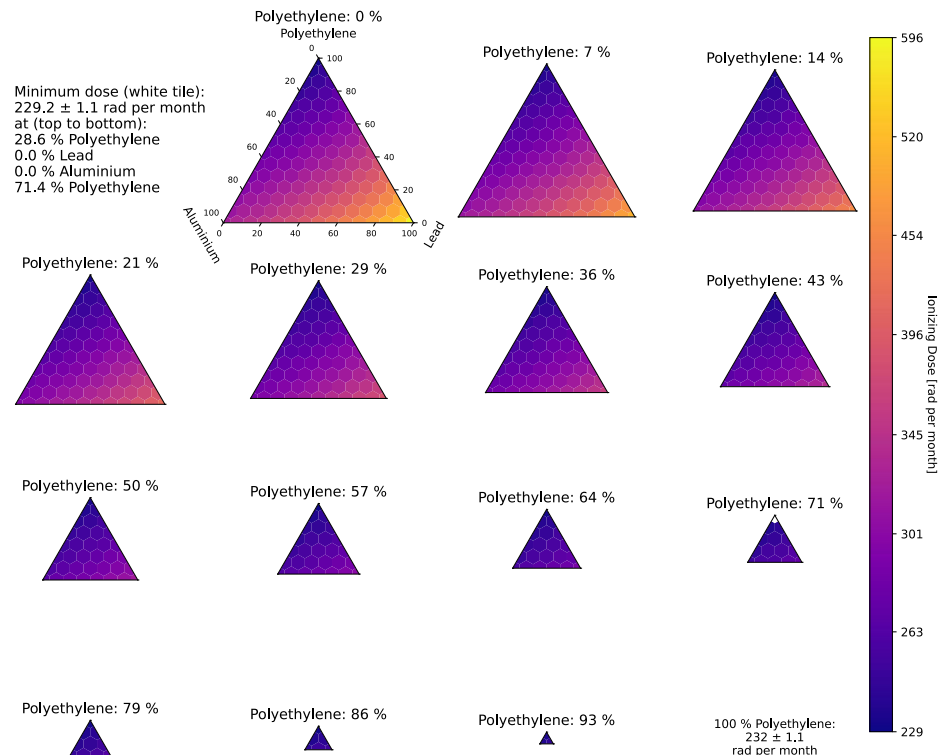
4-Layer Quaternary Mass Allocation

Electron dose behind Polyethylene-Lead-Aluminium-Polyethylene
one panel per Polyethylene mass share; ternary axes split the remaining mass



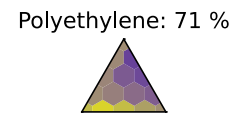
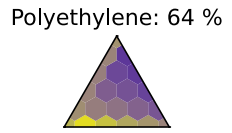
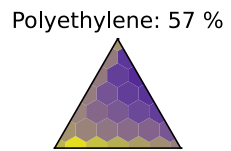
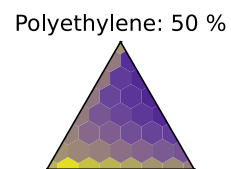
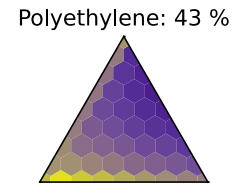
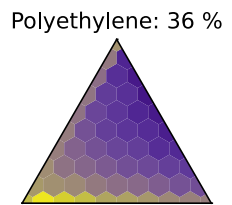
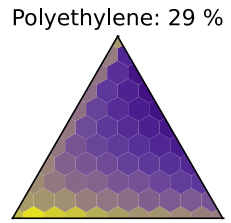
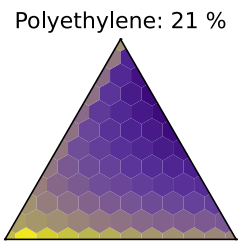
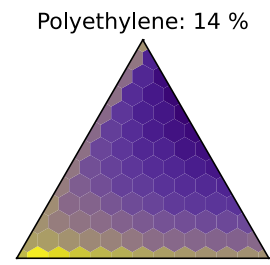
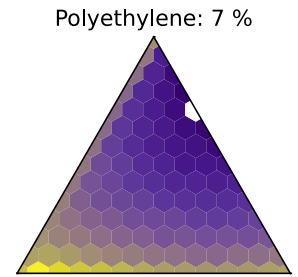
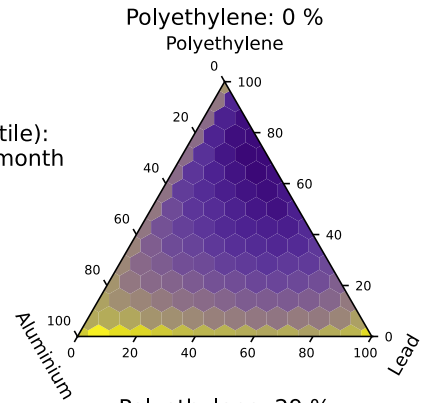
TID due to electrons on GTO

Proton dose behind Polyethylene-Lead-Aluminium-Polyethylene
one panel per Polyethylene mass share; ternary axes split the remaining mass



TID due to protons on GTO

Minimum dose (white tile):
 389.7 ± 0.35 rad per month
 at (top to bottom):
 64.3 % Polyethylene
 28.6 % Lead
 0.0 % Aluminium
 7.1 % Polyethylene



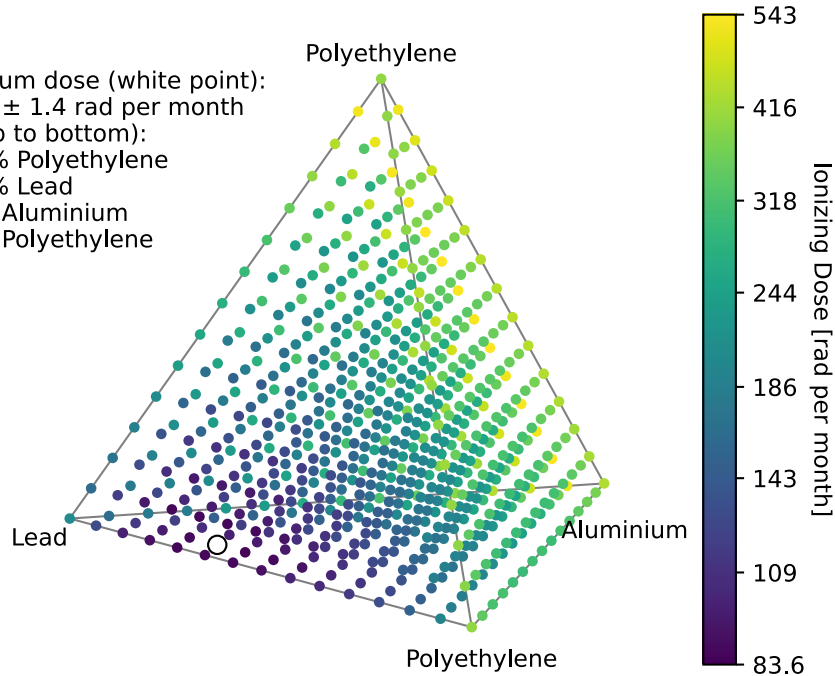
100 % Polyethylene:
 631.4 ± 6.3 rad per month



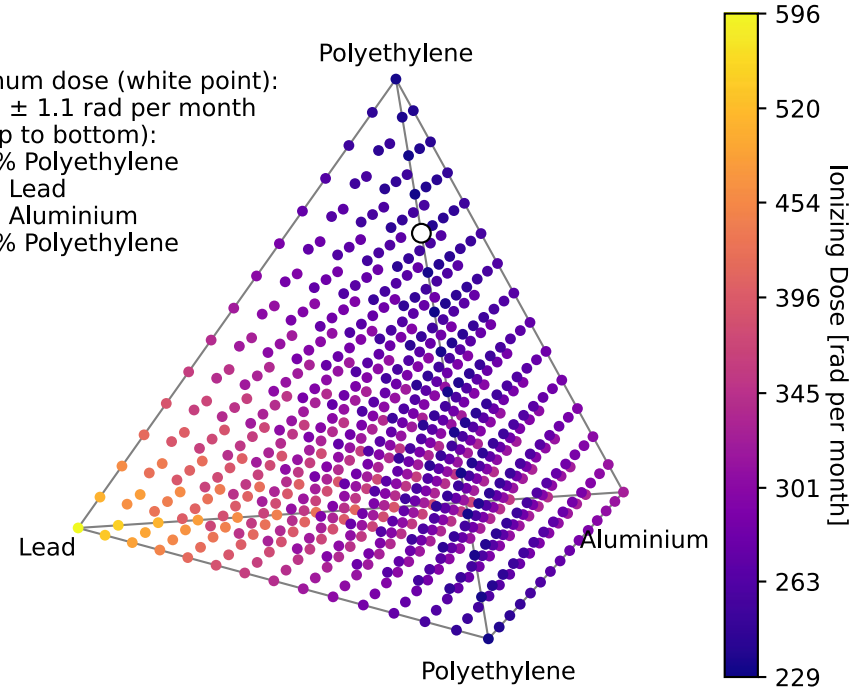
Multilayer Optimisation with MULASSIS

4-Layer Quaternary Mass Allocation

Minimum dose (white point):
 83.61 ± 1.4 rad per month
at (top to bottom):
28.6 % Polyethylene
64.3 % Lead
7.1 % Aluminium
0.0 % Polyethylene



Minimum dose (white point):
 229.2 ± 1.1 rad per month
at (top to bottom):
28.6 % Polyethylene
0.0 % Lead
0.0 % Aluminium
71.4 % Polyethylene

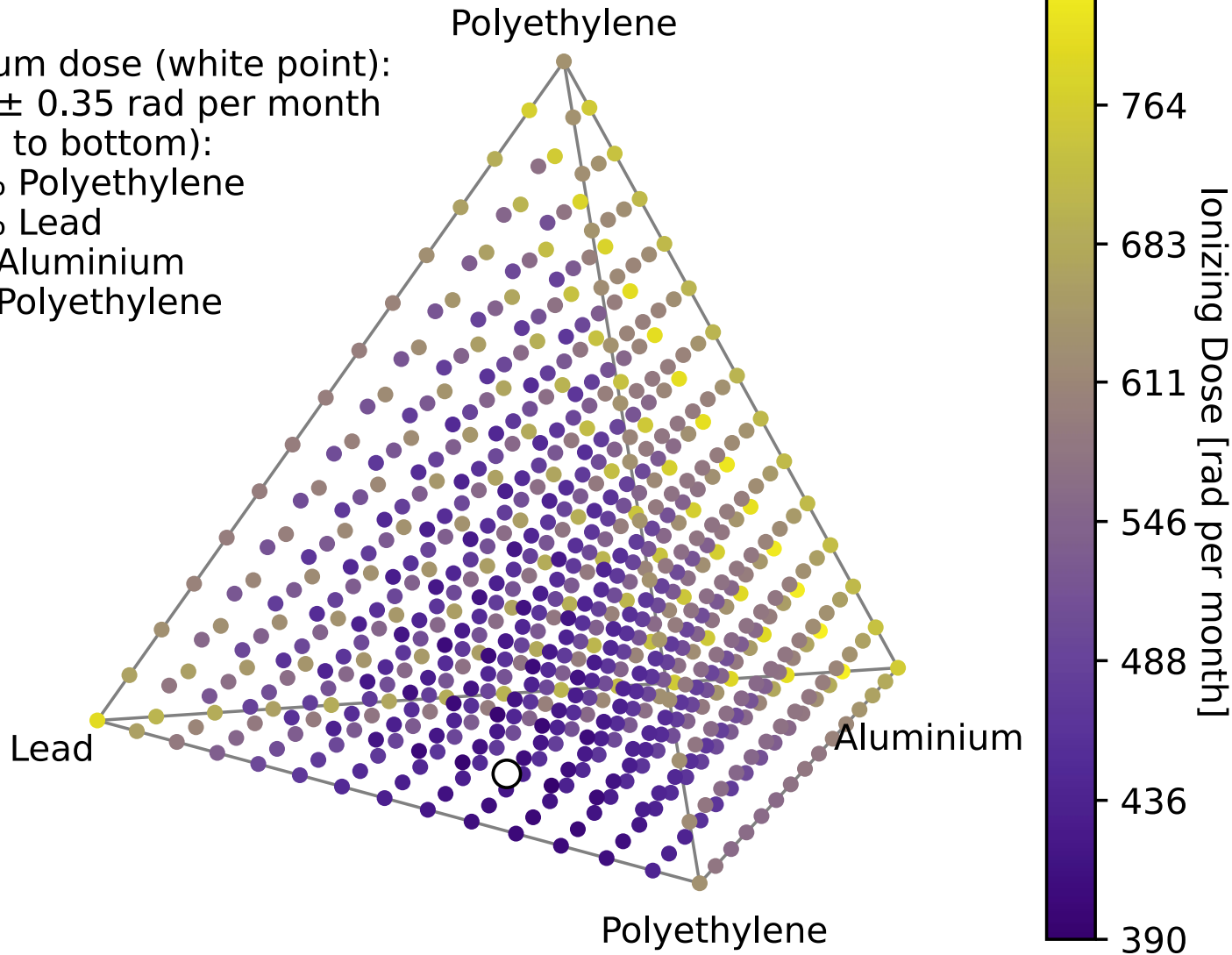


TID due to electrons on GTO

TID due to protons on GTO



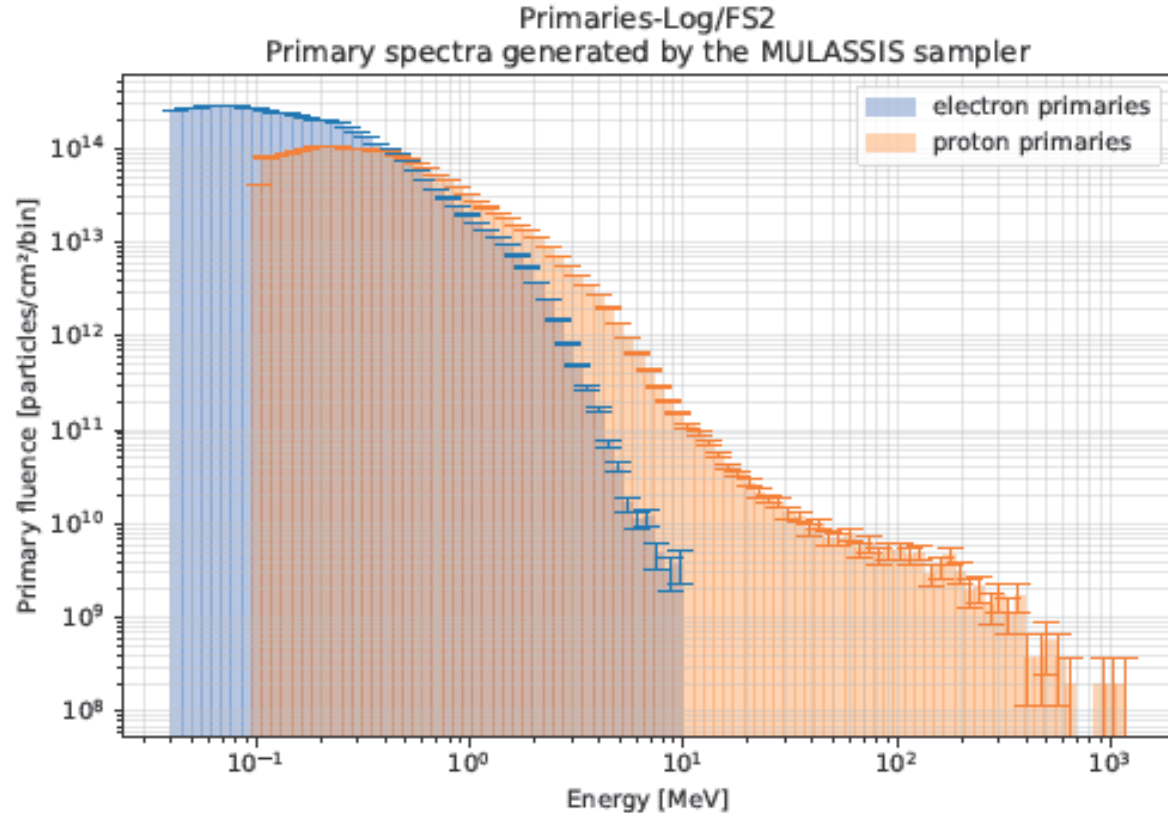
Minimum dose (white point):
389.7 ± 0.35 rad per month
at (top to bottom):
64.3 % Polyethylene
28.6 % Lead
0.0 % Aluminium
7.1 % Polyethylene



How to speed up the simulation?

Spectrum Biassing

- Space spectra are very steep
- > 6 orders of magnitude range in flux
- High energy tail poorly sampled



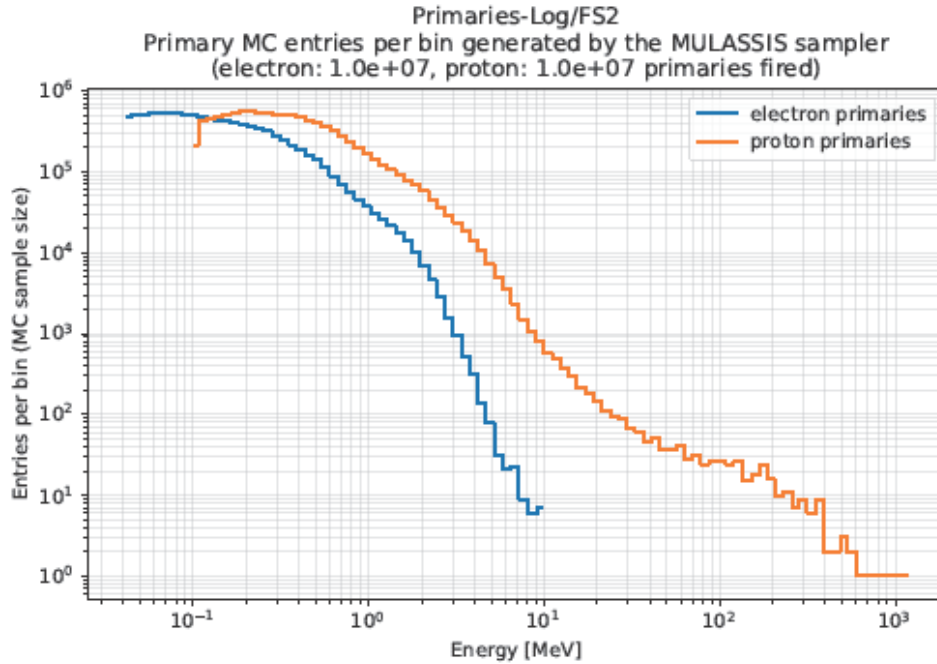
How to speed up the simulation

Spectrum Biassing

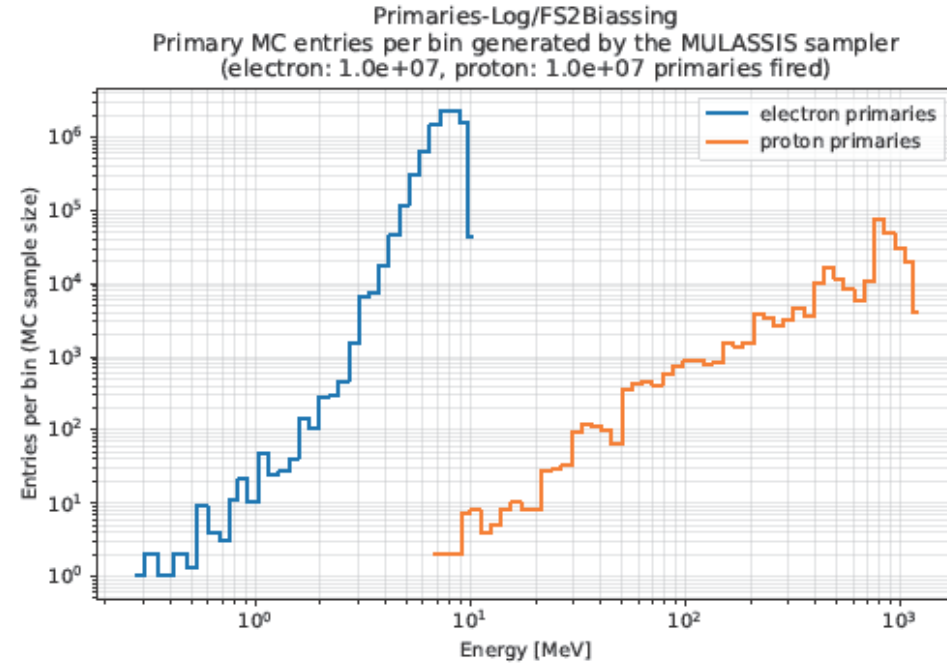
Source particle type and spectrum	
Environment:	Mission based <input type="button" value="v"/> average trapped particle fluence <input type="button" value="v"/>
Number of primary particles to simulate:	100 <input type="button" value="v"/>
Incident particle type:	proton <input type="button" value="v"/>
Incident energy spectrum	
Mission average spectrum	
Use <input type="button" value="v"/>	energy biassing
Interpolation type:	power-law <input type="button" value="v"/>
Angular distribution	
The angular distribution is omnidirectional.	

How to speed up the simulation

Spectrum Biassing



No Biassing

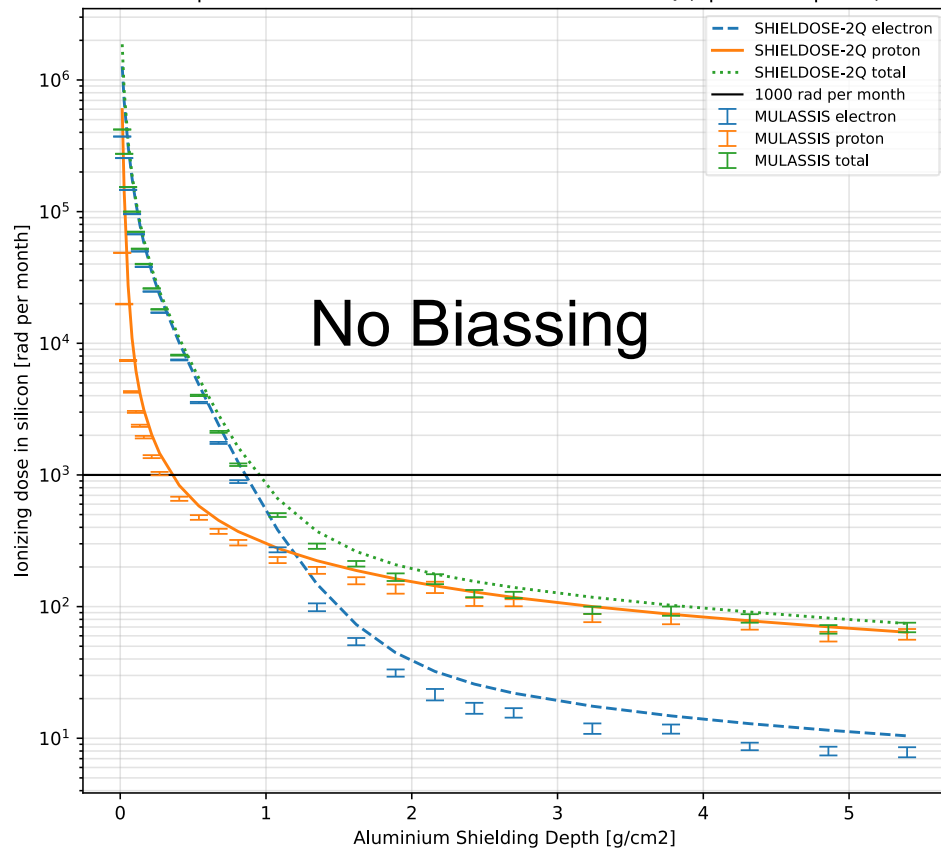


SPENVIS Biassing

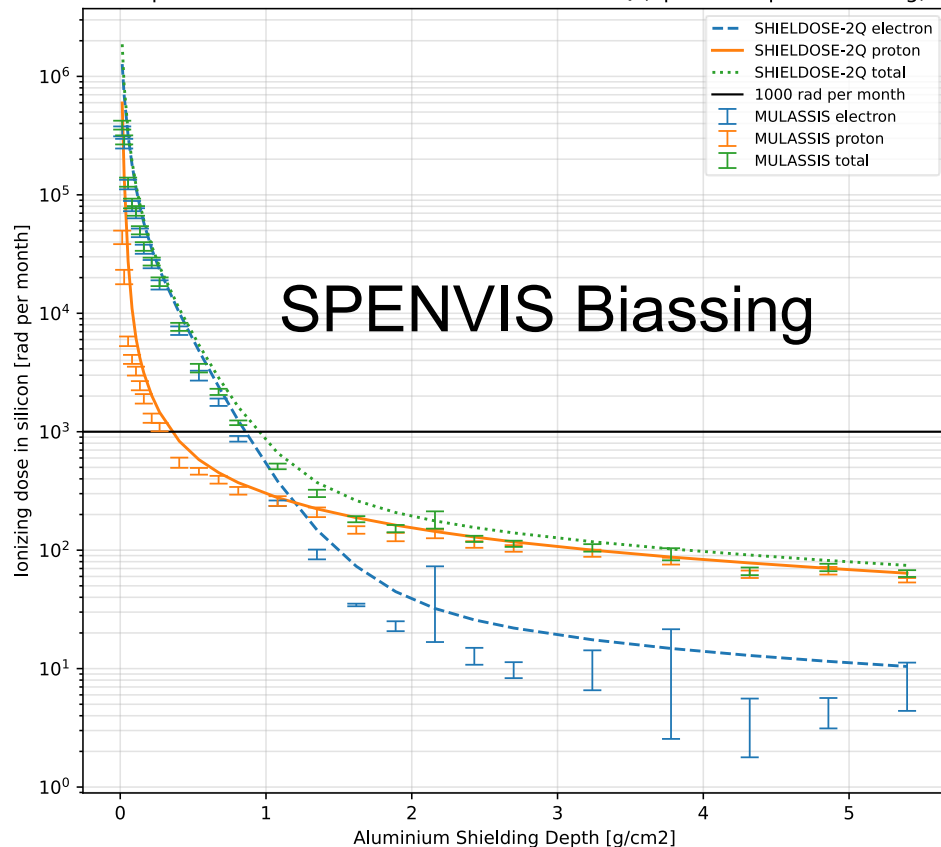
How to speed up the simulation

Spectrum Biassing

Comparison between Geant4 and SHIELDOSE-2Q (Spectra-10p/FS2)

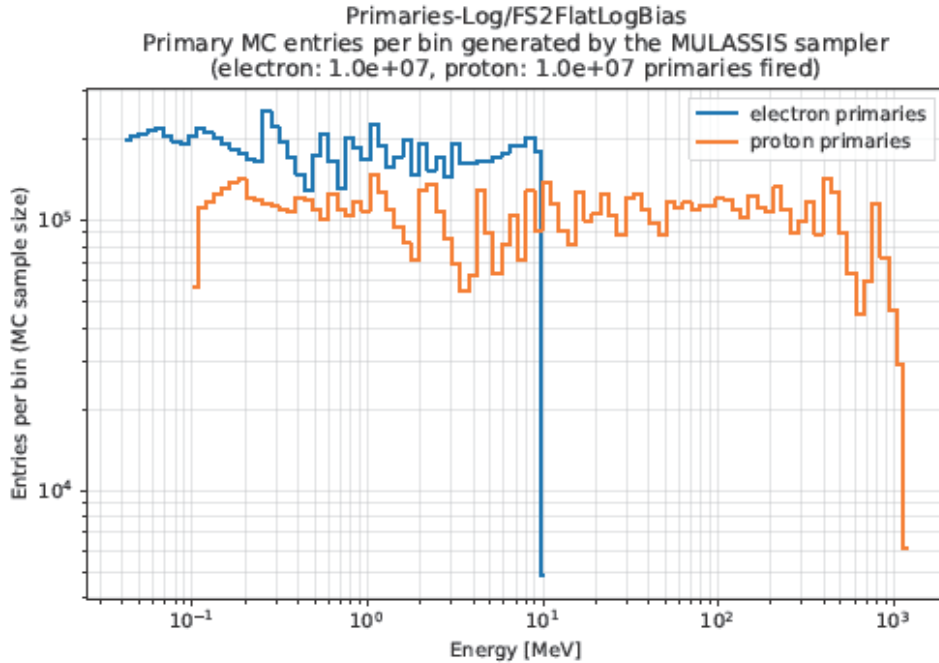


Comparison between Geant4 and SHIELDOSE-2Q (Spectra-10p/FS2Biassing)

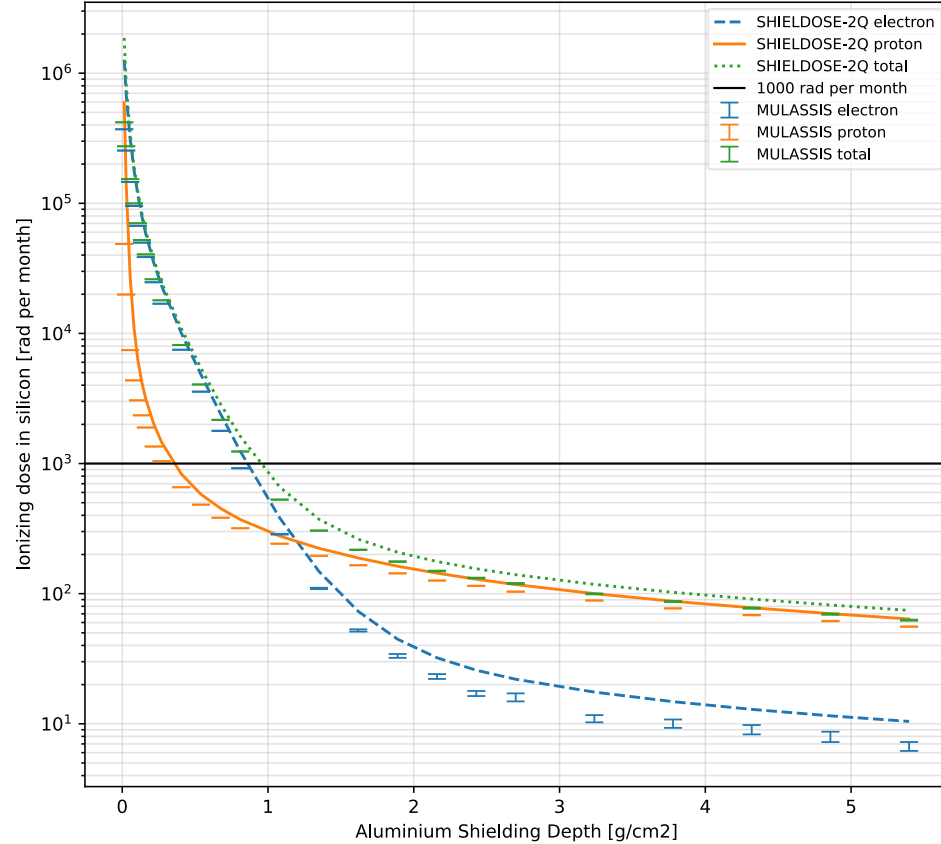


How to speed up the simulation

Spectrum Biassing



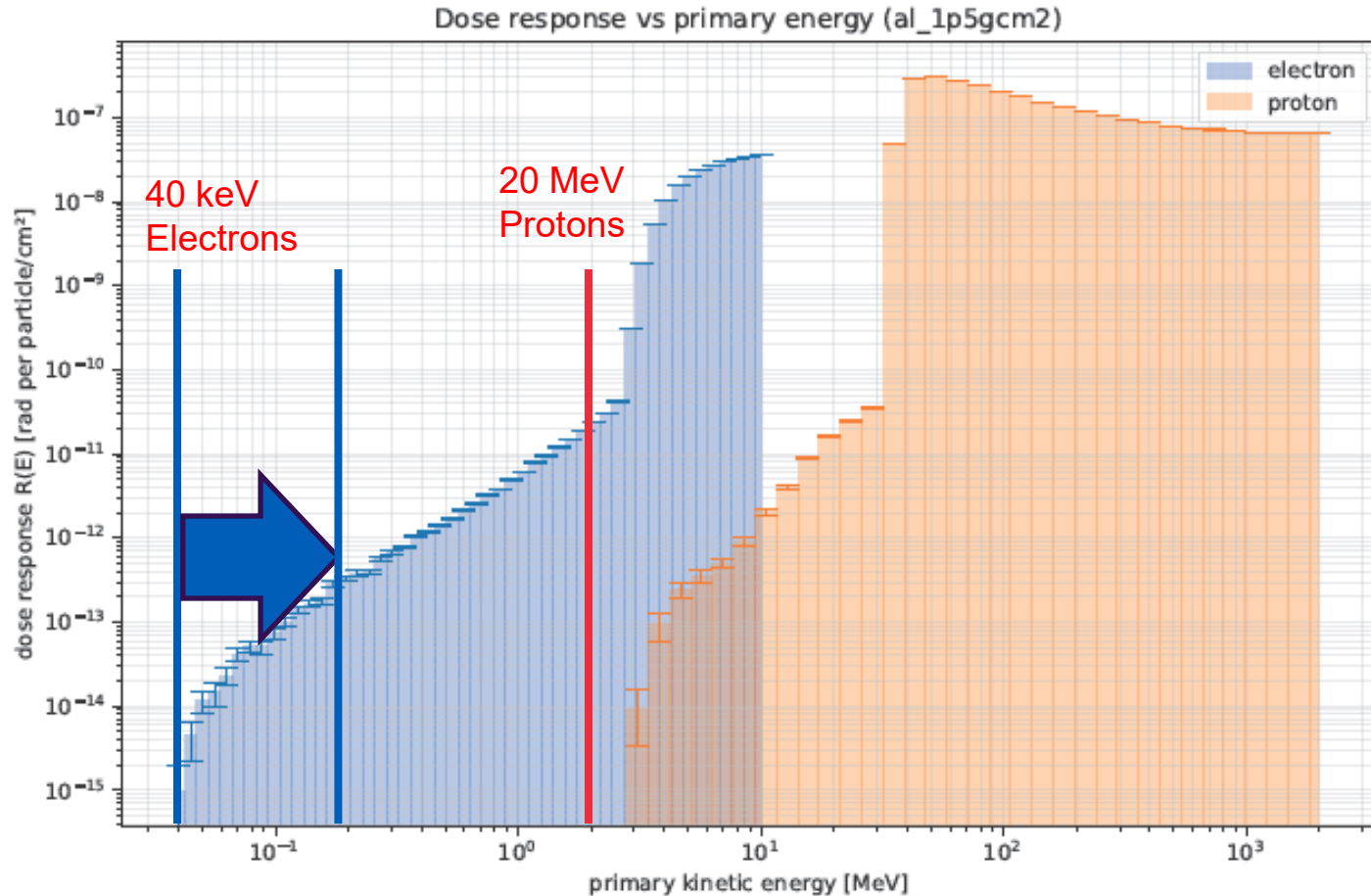
Comparison between Geant4 and SHIELDOSE-2Q (Spectra-10p/FS2FlatLogBias)



Manual Flat Log Biassing

How to speed up the simulation

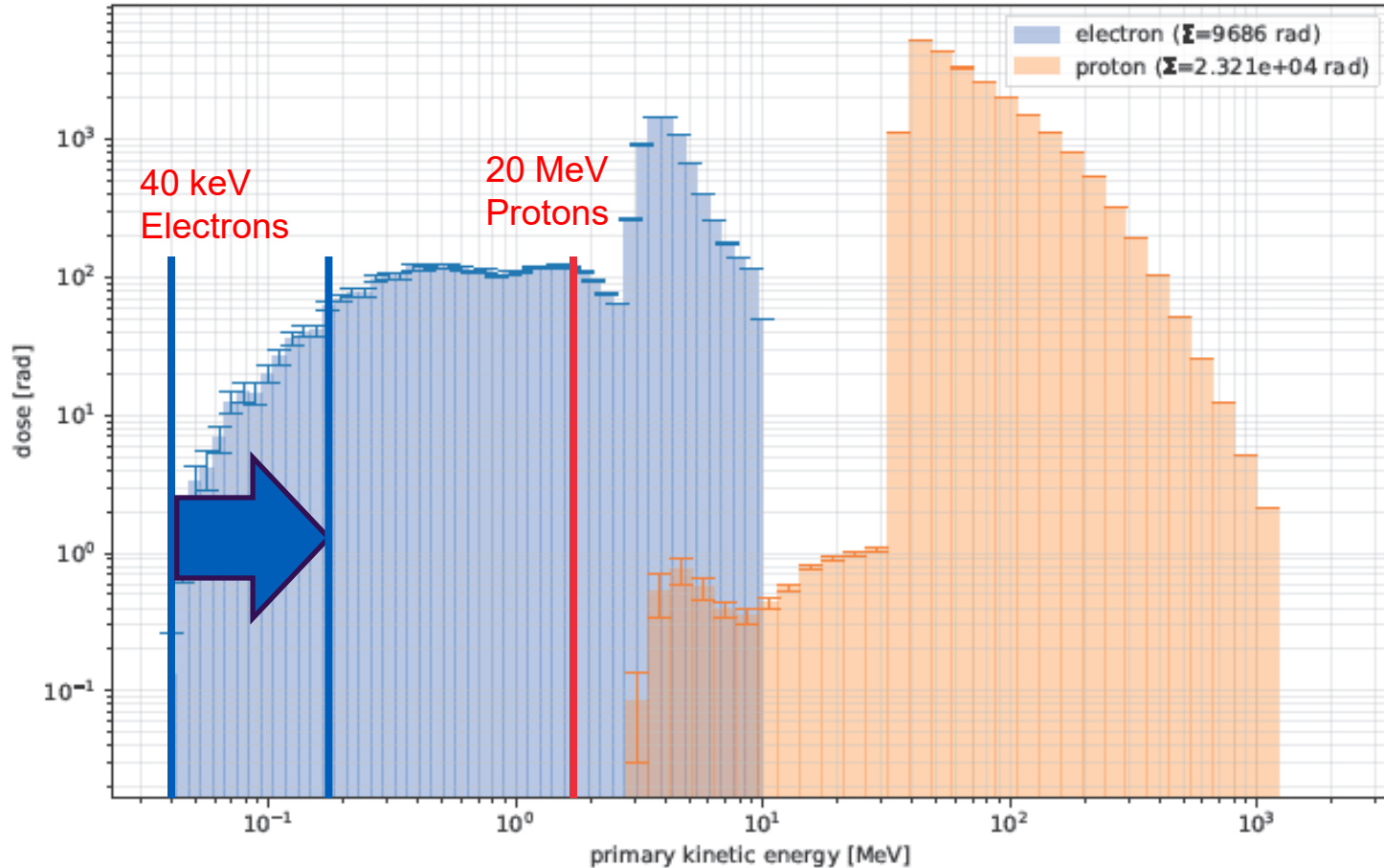
Spectrum Cutting



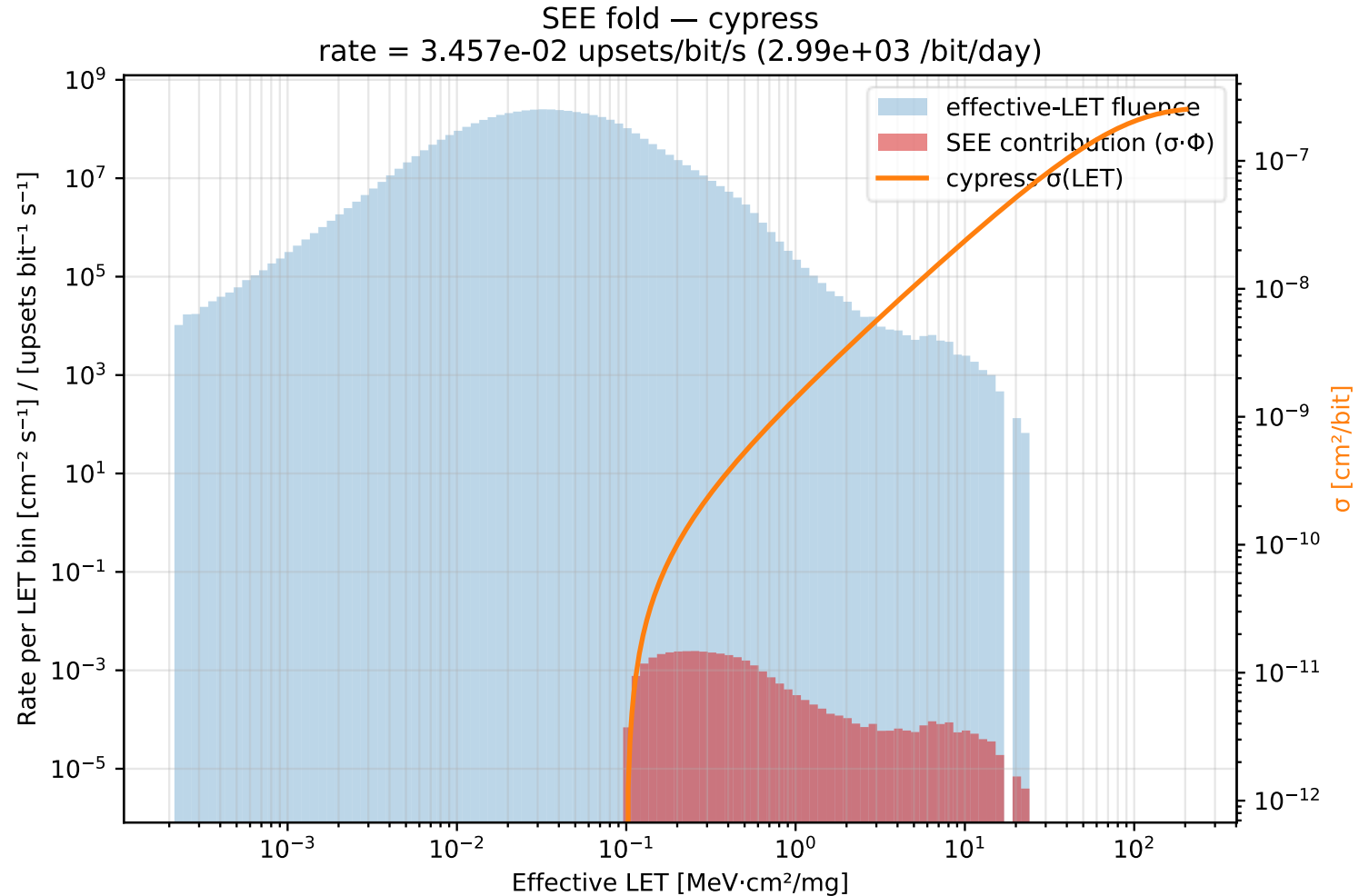
How to speed up the simulation

Spectrum Cutting

Dose vs primary energy — FS2 (GTO 11-year) | al_1p5gcm2



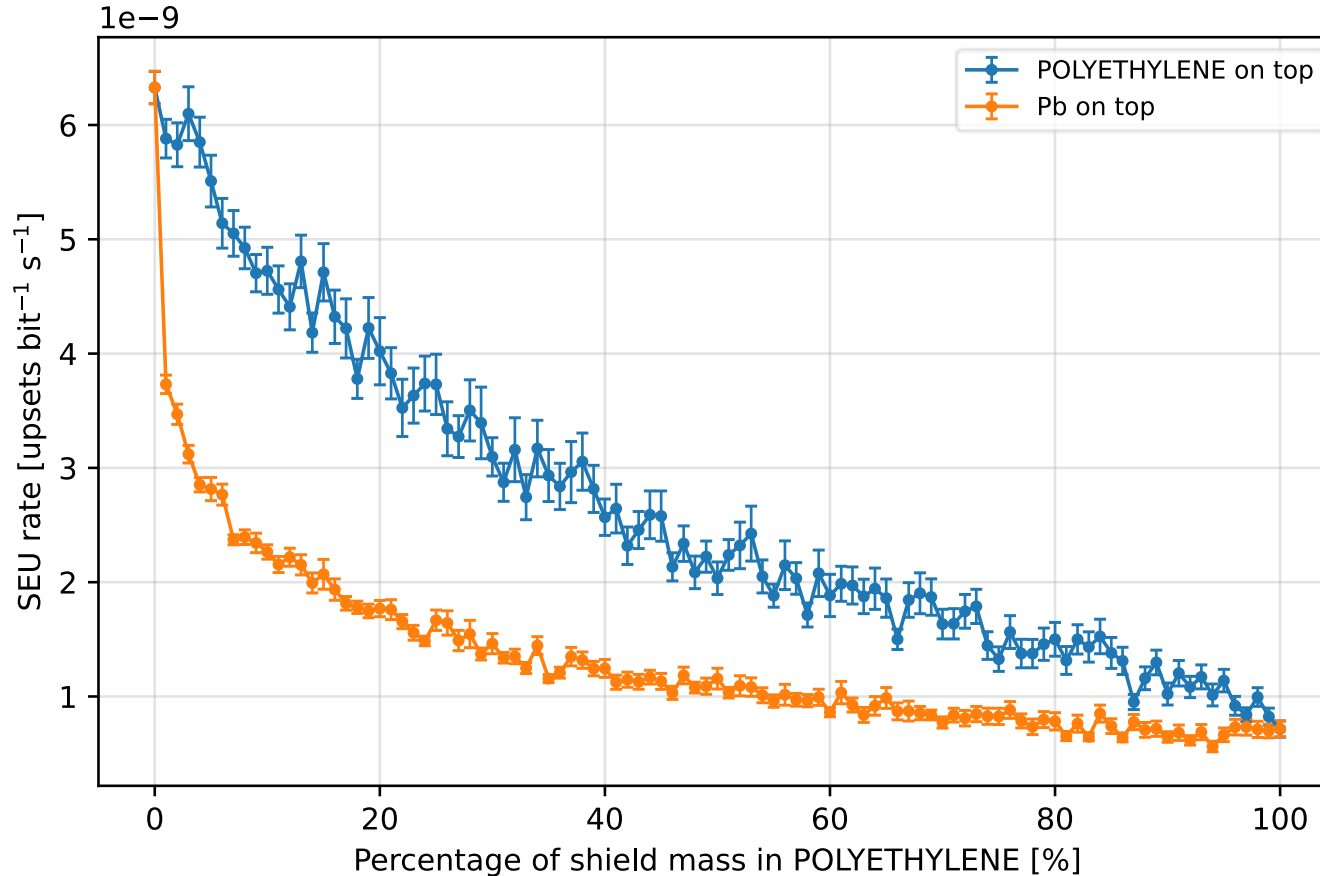
Multilayer Optimisation for SEE rate?



A?

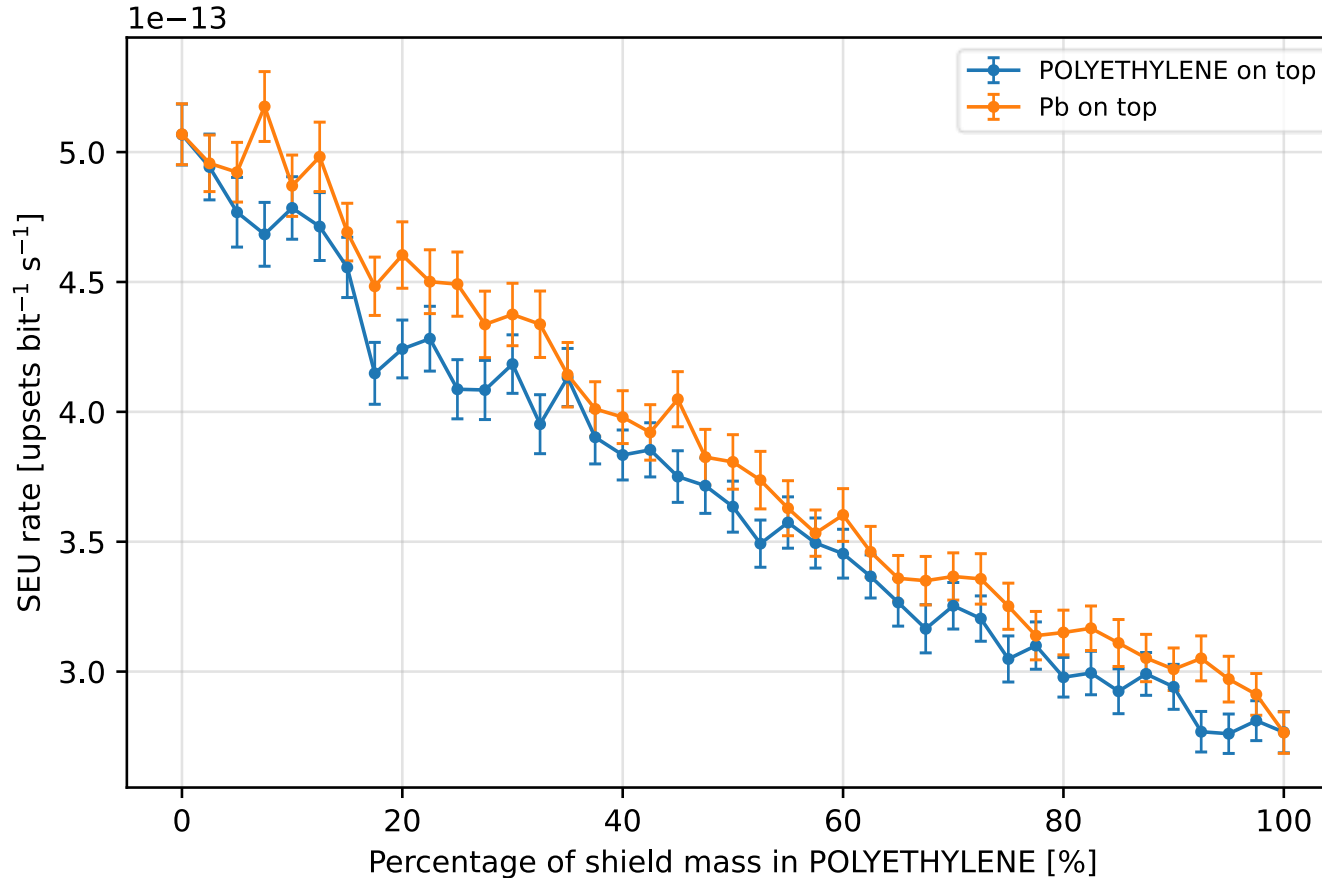
Multilayer Optimisation for SEE rate?

OldGTO trapped proton (AP9 flux), 1 g/cm² PE+Pb, 2 μm Si — Cypress CY62167
Min SEU rate $5.62\text{e-}10 \pm 4.6\text{e-}11$ /bit/s
at 6% Pb on top of POLYETHYLENE



Multilayer Optimisation for SEE rate?

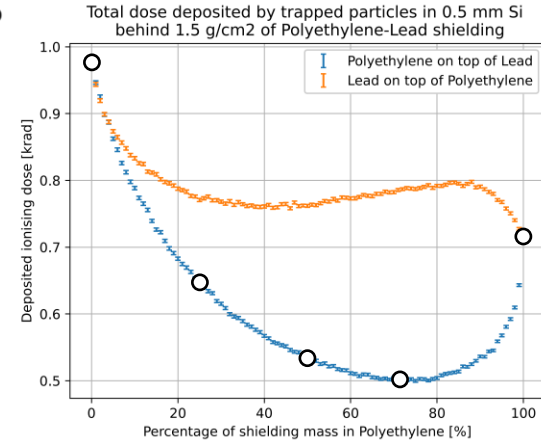
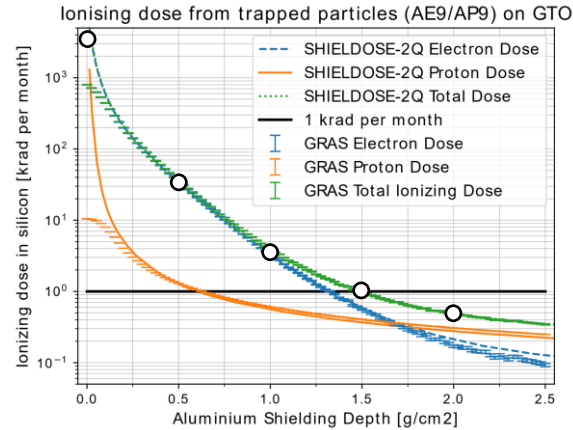
GEO cosmic iron (Fe-56, QBBC), 5 g/cm² PE+Pb, 2 μm Si — Cypress CY62167
Min SEU rate $2.761\text{e-}13 \pm 7.6\text{e-}15$ /bit/s
at 95% POLYETHYLENE on top of Pb



Foresail-2

Radiation Experiment

- Verify shielding simulations by measuring shielded doses in space
- Instrument prototype complete and validated in Co-60, proton and electron beam tests.
- We are searching for flight opportunities to the radiation belts





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(Multilayer Optimisation with GRAS/GDML)

Total ionising dose multilayer shielding optimisation for nanosatellites on geostationary transfer orbit

Anton Fetzer^{a,*}, Marius Anger^a, Philipp Oleynik^b, Jaan Praks^b

^a *Department of Electronics and Nanoengineering, Aalto University, Maarintie 8, Espo*

^b *Department of Physics and Astronomy, University of Turku, Vesilinnantie 5, Turku*

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GitHub Repository with my
MULASSIS code



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