Background simulation studies for the SuperCDMS experiment

CAP Congress 2026, Ottawa, Canada

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on behalf of the SuperCDMS collaboration

25th June 2026

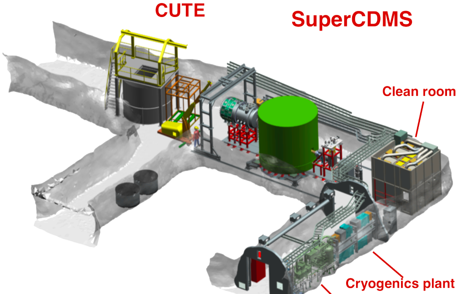
Outline

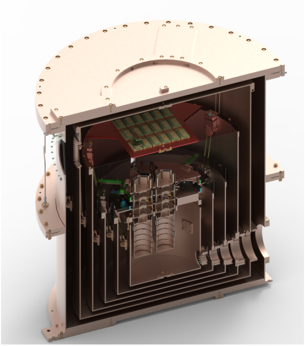
- SuperCDMS experiment at SNOLAB
- Overview of background types
- Implantation of ^{210}Pb due to exposure to Radon
- Cosmic ray induced muons
- Efficiency improvements with importance biasing

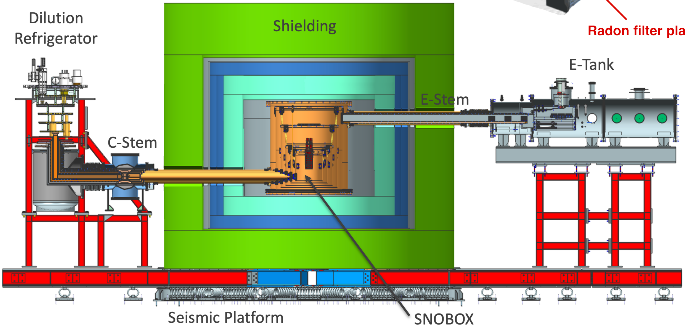
SuperCDMS experiment at SNOLAB

SuperCDMS experiment at SNOLAB

- The **Super C**roygenic **D**ark **M**atter **S**earch experiment is aiming for direct detection of DM interactions.
- Complementary technique using 18 Ge and 6 Si detectors under cryogenic conditions.
- Commissioning started in January 2026.







Background types in SuperCDMS

Background types in SuperCDMS

- **Radioactive contamination**
- Cosmogenic activation
- Cosmic ray induced muons
- Dust on surfaces
- Radon exposure

- Long-lived radioactive isotopes are contained in traces in all materials.
- Some of those isotopes make up the beginning of natural decay chains: ^{232}Th, ^{238}U, ^{235}U

- Bananas are a good source of Potassium, also containing 100 mBq/g of ^{40}K.
- SuperCDMS detector housings made of Cu only contain 0.31 mBq/g of ^{40}K.

Background types in SuperCDMS

- Radioactive contamination
- **Cosmogenic activation**
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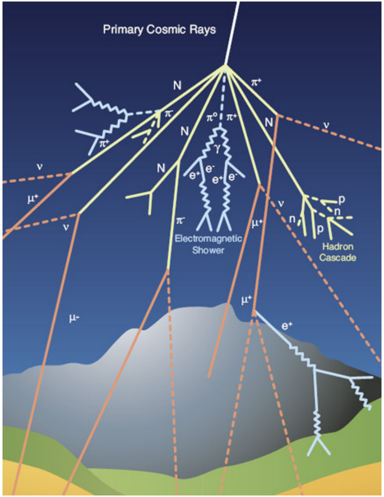
- Neutron, protons, muons from cosmic ray showers can activate materials.
- Spallation by high energy neutrons (∼ MeV):
  ^{63}Cu(n,α)^{60}Co
  ^{70}Ge(n,t)^{68}Ga
- Absorption of thermal neutrons (∼ meV):
  ^{70}Ge(n,γ)^{71}Ge



Background types in SuperCDMS

- Radioactive contamination
- Cosmogenic activation
- **Cosmic ray induced muons**
- Dust on surfaces
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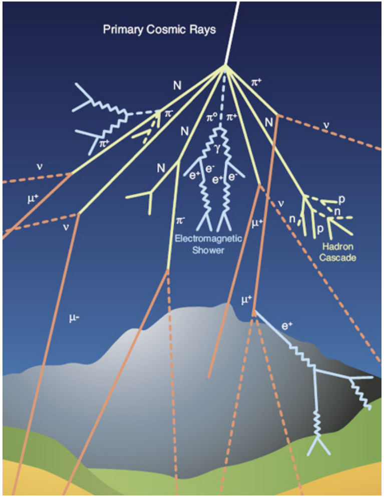
- SNOLAB is 2 km deep, reducing the muon flux to $\sim 2\ \mu\ /\ m^2\ /$ week.
- Muons can create EM and hadronic showers inside the rock surrounding the lab.
  - High-energy γ-rays and neutrons can traverse the experiment.

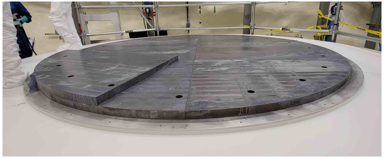


Background types in SuperCDMS

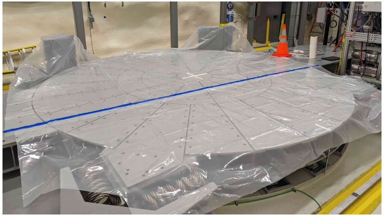
- Radioactive contamination
- Cosmogenic activation
- Cosmic ray induced muons
- **Dust on surfaces**
- Radon exposure

- SNOLAB is a class 2000 clean room: $<$ 2000 particles (0.5 µm or larger) per cubic foot of air.
- During construction dust may fall on surfaces.
- Dust is collected in vials to monitor its radioactive content.

Lead shield installation



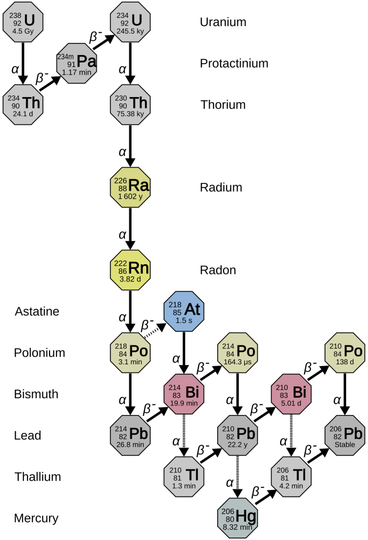
Covered seismic platform



Background types in SuperCDMS

- Radioactive contamination
- Cosmogenic activation
- Cosmic ray induced muons
- Dust on surfaces
- **Radon exposure**

- Radioactive ^{222}Rn is contained in air, outgassing from matter (e.g. rock at SNOLAB).
- Progenies of ^{222}Rn can adhere to aerosol particles or surfaces which are exposed to air.



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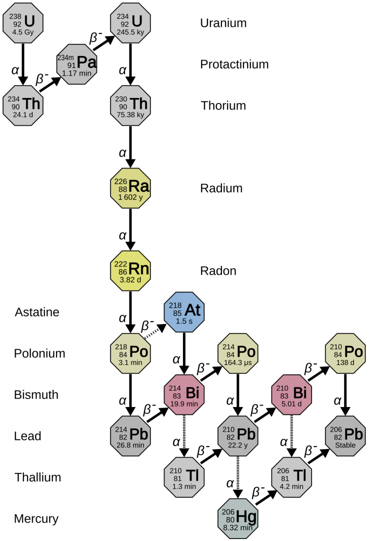
Implantation of ^{210}Pb due to exposure to Radon

Implantation of ^{210}Pb due to exposure to Radon

- Daughter nuclides of the α-decays of ^{222}Rn, ^{218}Po and ^{214}Po get sufficient momentum from the nuclear recoil to implant them into the surface of a material.
- ^{210}Pb has a long half-life (22.2 yr), so it accumulates over time while the material is exposed to air.
- Need to determine the implantation depth profile of ^{210}Pb to model its contribution to the overall background budget.



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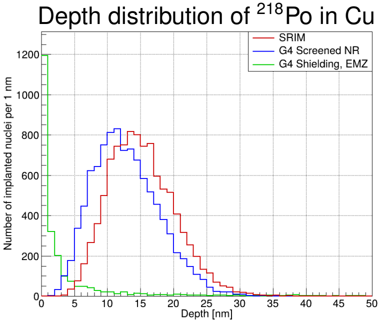
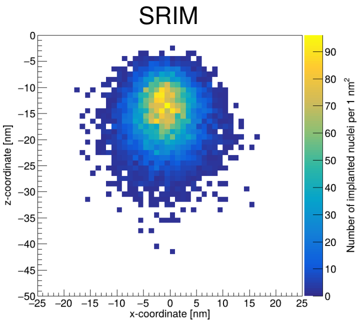
Comparison between SRIM and GEANT4

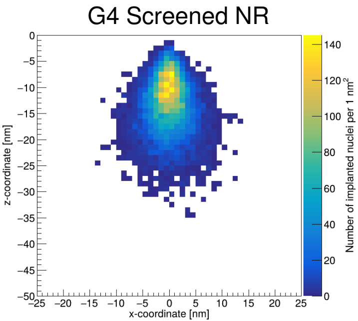
- Shoot nuclei with their corresponding recoil energy from α-decay onto various materials.
- Record depth of stopped nuclei as distance to closest surface.
- Compare SRIM [1] and GEANT4's Screened Nuclear Recoil Physics List [2].



Depth distribution of ^{218}Po in Cu



SRIM



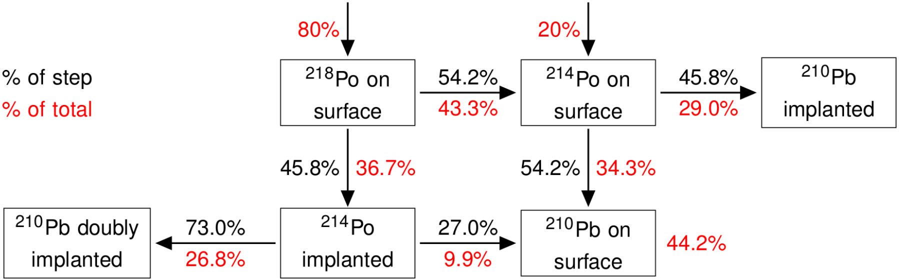
G4 Screened NR

[1] Ziegler and Biersack, NIM B 268 (2010) 1818

[2] Mendenhall and Weller, NIM B 227 (2005) 420

^{222}Rn progenies on material's surfaces

- The ratio of ^{218}Po vs. ^{214}Po adhering on a material's surface depends on the isotopes half lives, diffusion velocity of radon daughters and ventilation rate of the air.
- GEANT4 can simulate the full decay chain, isotropic emission of decay products, which may lead to ^{210}Pb being doubly implanted.
- The initial ratio of ^{218}Po vs. ^{214}Po on surfaces and the ratio of ^{210}Pb being implanted vs. on surface is material independent.



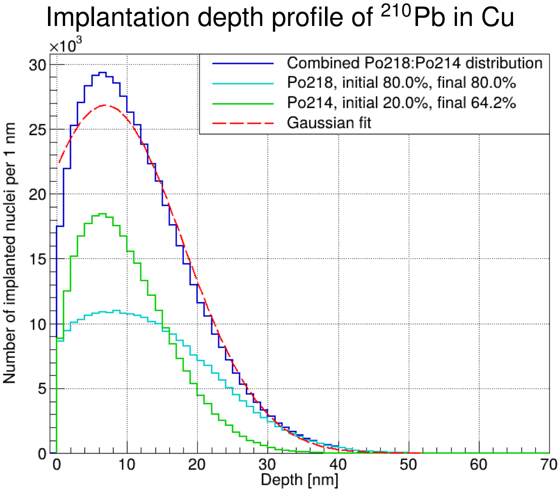
% of step
% of total

80% → ^{218}Po on surface
20% → ^{214}Po on surface

^{218}Po on surface → ^{214}Po on surface: 54.2% / 43.3%
^{214}Po on surface → ^{210}Pb implanted: 45.8% / 29.0%
^{218}Po on surface → ^{214}Po implanted: 45.8% / 36.7%
^{214}Po on surface → ^{210}Pb on surface: 54.2% / 34.3%
^{214}Po implanted → ^{210}Pb doubly implanted: 73.0% / 26.8%
^{214}Po implanted → ^{210}Pb on surface: 27.0% / 9.9%
^{210}Pb on surface: 44.2%

Implantation depth profiles

- Combine ^{210}Pb implantation depth profiles from ^{218}Po and ^{214}Po on surfaces according to the determined ratio.
- For background simulation studies, draw the depth distribution from the profile, or sample from a simple Gaussian function.
- Investigate surface or fiducial volume cuts and compare to measured data.
  - In SuperCDMS, α-particles, β-electrons, γ-rays can reach a neighboring detector if the decay occurred near the surface.

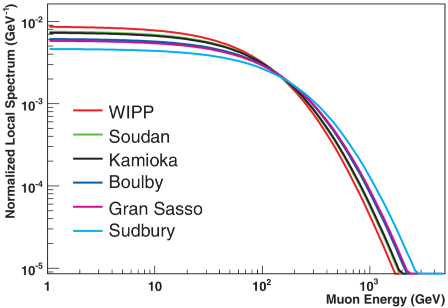


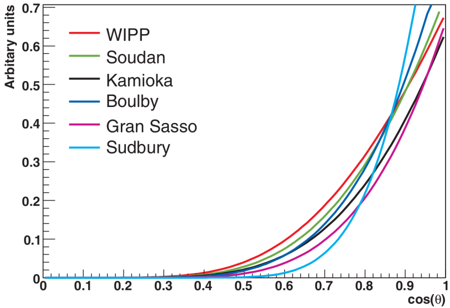
Cosmic ray induced muons

Cosmic ray induced muons

Parametrization by Mei and Hime, PRD 73, 053004 (2006):

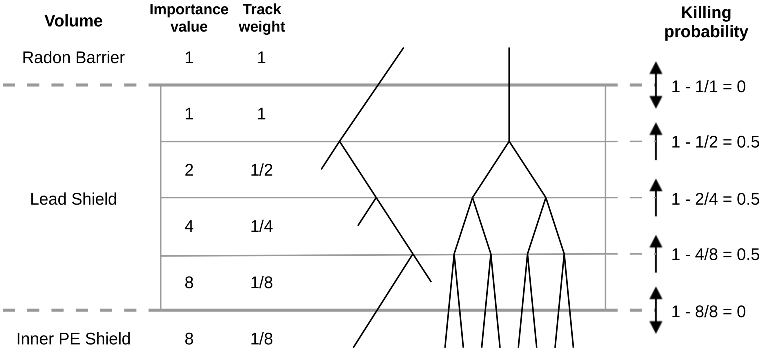
- Generate muons with energy and momentum direction following energy spectra and angular distribution from functions taking into account the depth of the laboratory.
- Energy and momentum direction are correlated in reality.
- Muons need to travel $>$ 3 m through norite rock to produce a constant shower of particles.





Efficiency improvements with importance biasing

Importance Biasing



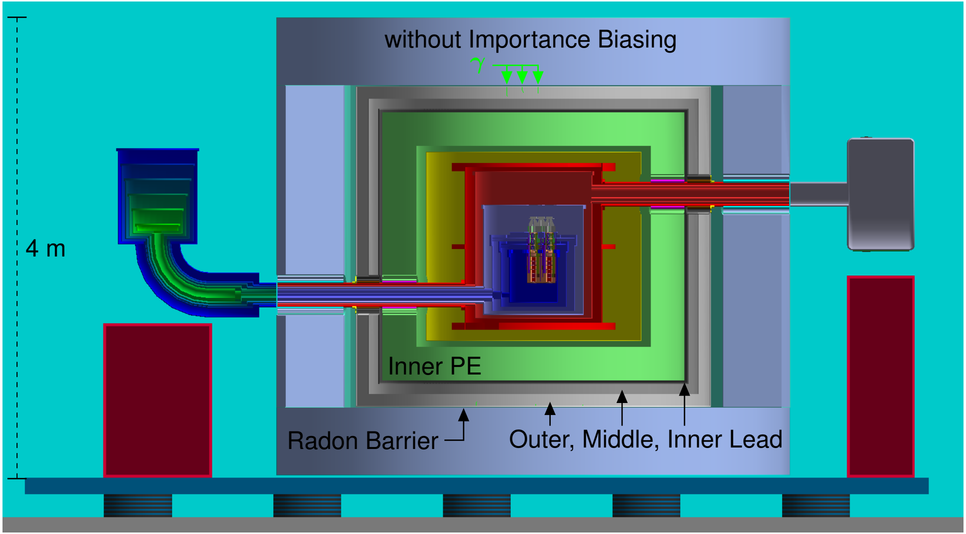
Volume	Importance value	Track weight
Radon Barrier	1	1
Lead Shield	1	1
	2	1/2
	4	1/4
	8	1/8
Inner PE Shield	8	1/8

Killing probability

1 - 1/1 = 0
1 - 1/2 = 0.5
1 - 2/4 = 0.5
1 - 4/8 = 0.5
1 - 8/8 = 0

- GEANT4’s importance biasing splits (kills) particles going to (away from) the detectors.
- The split particle is an identical copy of the original particle, both their weights are halved.
- A backwards going particle is either killed or its weight is adjusted.
- Only one particle type is biased, i.e. in our case gammas inside the lead shield.

Particle propagation in comparison



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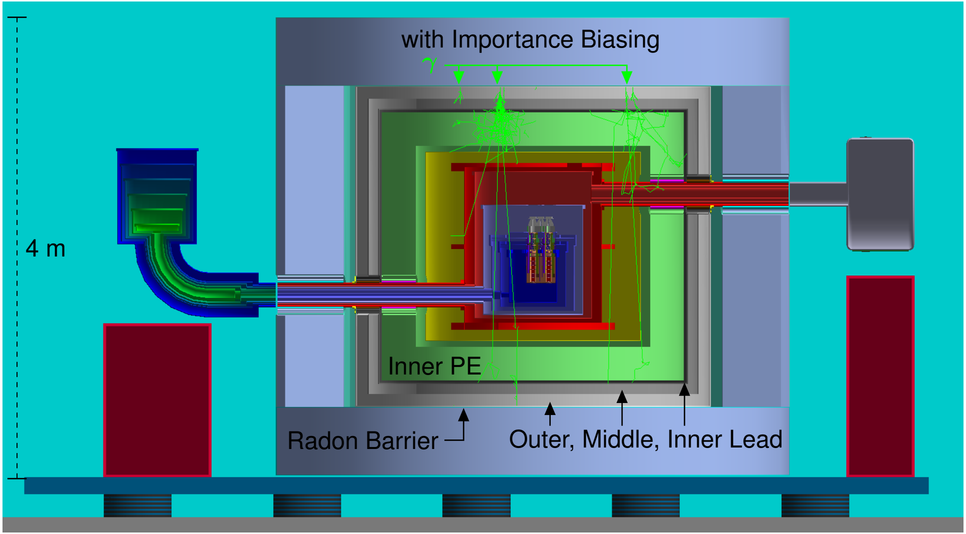
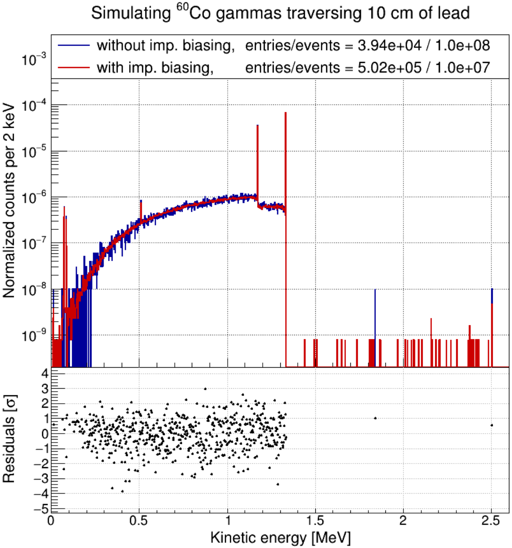


Efficiency of Importance Biasing



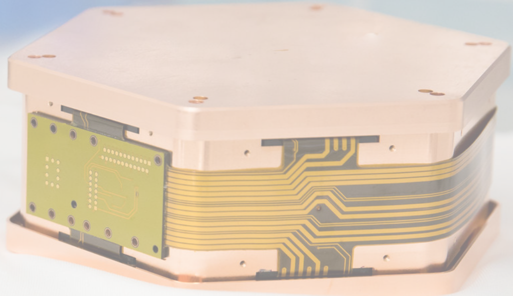
- Validate importance biasing scheme and estimate efficiency boost with a simplified geometry.
- Record all particle tracks leaving the Lead Shield.
- Biased simulation run with importance layer thickness of 1.25 cm.

Lead shield thickness	Number of layers	Efficiency boost
10 cm	8	131.6 ± 0.7
20 cm	16	$(49.8 \pm 7.6) \cdot 10^3$

► Efficiency improvement strongly depends on the number and thickness of importance layers.

Conclusion

- Modeling the ^{210}Pb from radon exposure is possible and convenient with GEANT4.
- Propagating muons requires a minimum distance traveled through rock to ensure a constant shower of secondaries.
- Applying importance biasing in background simulations achieves a significant efficiency boost enabling us to:
  - generate sufficient statistics for observed detector spectra to model our background
  - while needing much less computing time.



"Applying Geant4's importance biasing to improve the efficiency of SuperCDMS background simulations"
NIM A 1080 (2025) 170766

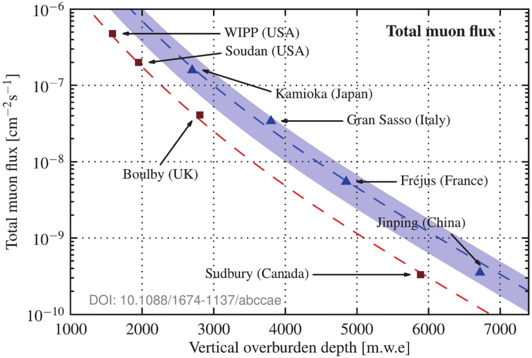
Backup

SuperCDMS Collaboration

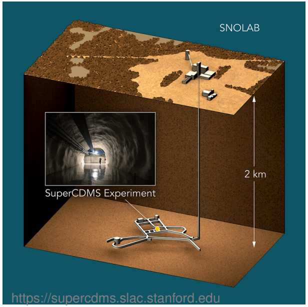
https://supercdms.slac.stanford.edu

SNOLAB underground facility

- Located in Sudbury, Canada, in an active mine.
- Rock overburden of 2 km shields from cosmic radiation.
- Muon flux reduced by a factor of 50 million compared to surface.
- Hosting DM and neutrino experiments in need of low background environment.



DOI: 10.1088/1674-1137/abccae



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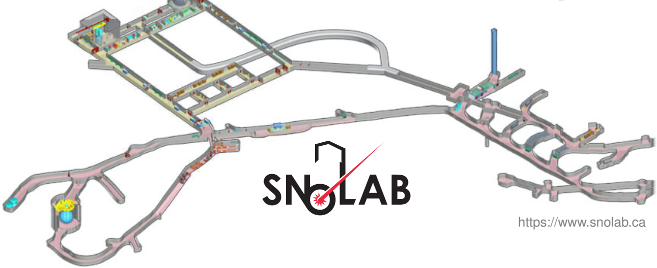
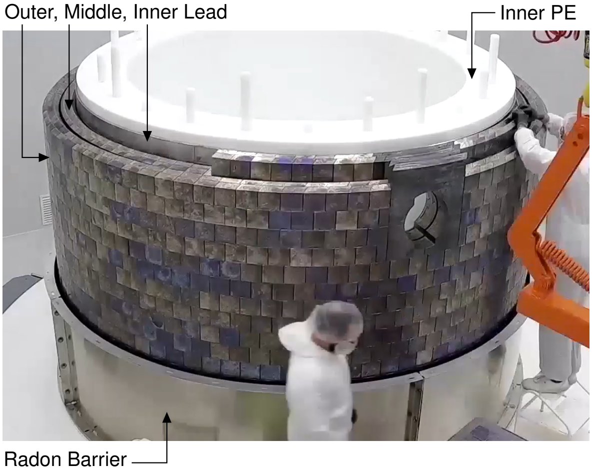


https://www.snolab.ca

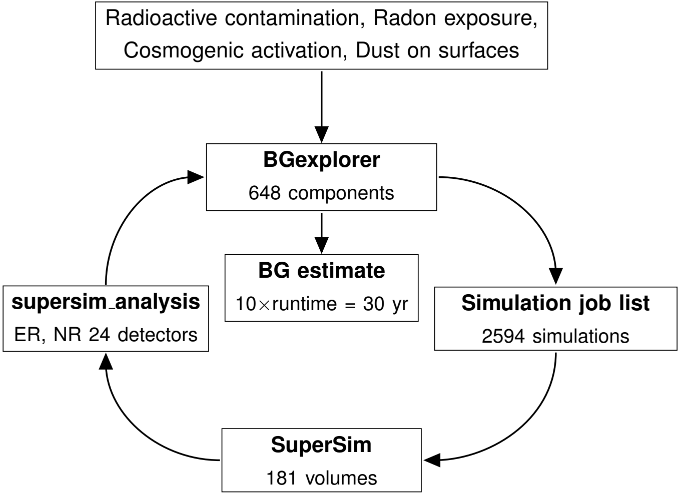
SuperCDMS lead shield

- Graded lead shield:
  - Regular background (Outer):
    10 - 20 cm – 117 Bq/kg
  - Low background (Middle):
    1 - 10 cm – 16 Bq/kg
  - Ultra low background (Inner):
    0 - 1 cm – 0.2 Bq/kg
- Simulating radioactive contaminations inside the lead shield (e.g. ^{210}Pb) or in volumes surrounding the lead shield (e.g. ^{40}K in radon barrier) would consume $\sim \mathcal{O}$(10k) of cpu years.



Background simulation campaign for SuperCDMS

- Screen each component to get assays of contained radioactive isotopes.
- Monitor component's time on Earth's surface, exposure time to mine air, time in clean room accumulating dust.
- BGexplorer calculates the emission rate for each component and isotope.
- SuperCDMS' GEANT4 application SuperSim propagates emitted particles through setup and records detector hits.
- BGexplorer calculates component's BG contribution from processed spectra.



Radioactive contamination, Radon exposure, Cosmogenic activation, Dust on surfaces

BGexplorer
648 components

BG estimate
10×runtime = 30 yr

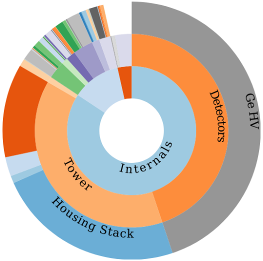
Simulation job list
2594 simulations

SuperSim
181 volumes

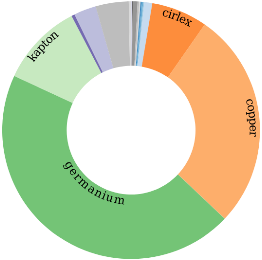
supersim_analysis
ER, NR 24 detectors

Background estimate from BGexplorer

component



material



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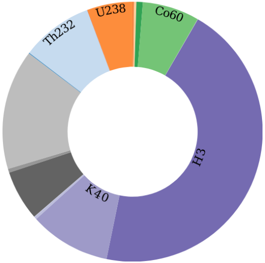

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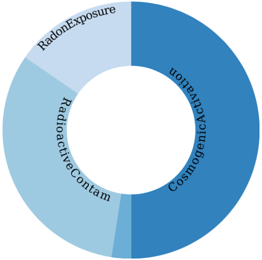
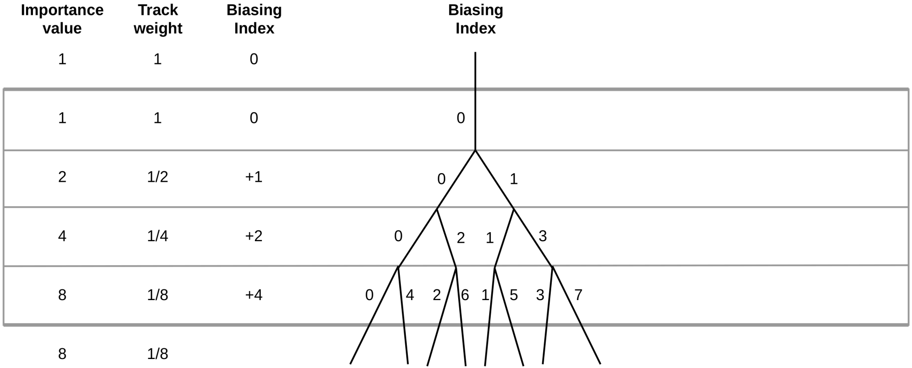


https://github.com/bloer/bgexplorer

- BGexplorer provides a background estimate based on material assay results.
- Visualizes the BG contribution in pie charts, spectra and tables.
- Enables easy identification of dominating BGs.

Event Numbering – Biasing Index



Importance value	Track weight	Biasing Index
1	1	0
1	1	0
2	1/2	+1
4	1/4	+2
8	1/8	+4
8	1/8	

- Distinguish between different split-track topologies within a single generated event.
- The *Biasing Index* of a split particle is increased according to the original particle's *Biasing Index* and the importance value of the just entered importance layer.

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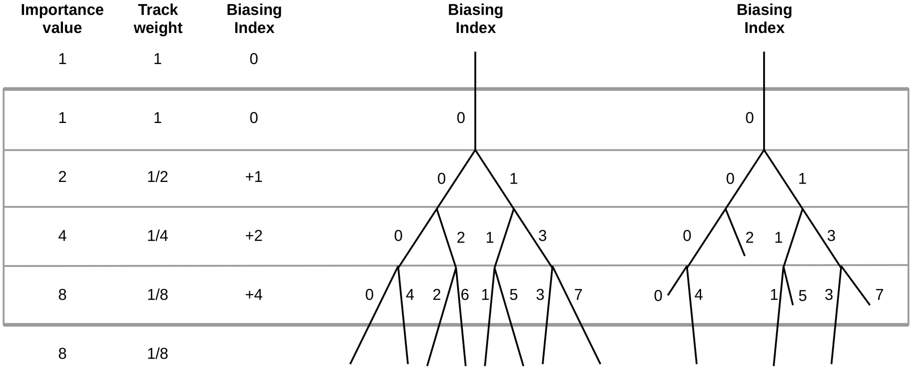

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- Distinguish between different split-track topologies within a single generated event.
- The *Biasing Index* of a split particle is increased according to the original particle’s *Biasing Index* and the importance value of the just entered importance layer.
- Sum up detector hits for same *Biasing Index* and weight with track weight.

Efficiency of Importance Biasing

- Contaminate Radon Barrier with isotopes, count detector hits with/without Importance Biasing.

Primary	Simulated events		Detector hits		Runtime [h]		Efficiency boost $[10^3]$
	imp. bias.	no bias	imp. bias.	no bias	imp. bias.	no bias	
^{40}K	10^7	$2 \cdot 10^{10}$	35	4	2.6	3454	12.4 ± 6.5
^{60}Co	10^7	10^{10}	175	10	14.4	5900	7.5 ± 2.4
^{232}Th	10^7	10^{10}	2063	75	27.1	12123	13.7 ± 1.6

- Importance layer thickness needs to be adjusted depending on the gamma energy.
- Very tricky choice for isotopes emitting different gamma energies, especially in decay chains.
- SuperCDMS' backgrounds include e.g. ^{210}Pb emitting a 46 keV γ and ^{232}Th with a 2.6 MeV γ.
- Determine optimal importance biasing settings with simulation studies for effective simulations.