Background simulations for the SuperCDMS experiment – Efficient GEANT4 simulations using Importance Biasing

TAUP Conference, Vienna, Austria

Birgit Zatschler
on behalf of the SuperCDMS collaboration

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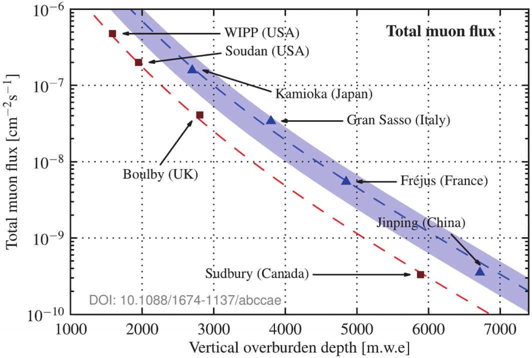
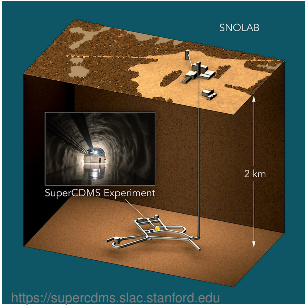
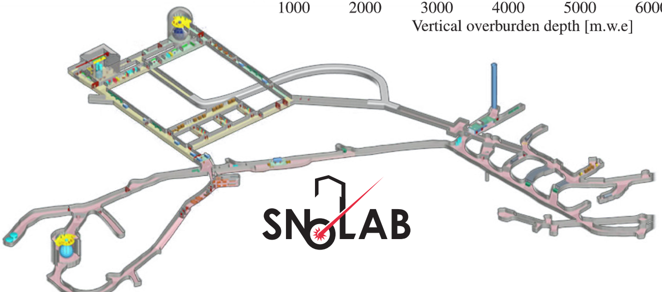
SNOLAB underground facility

- 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.





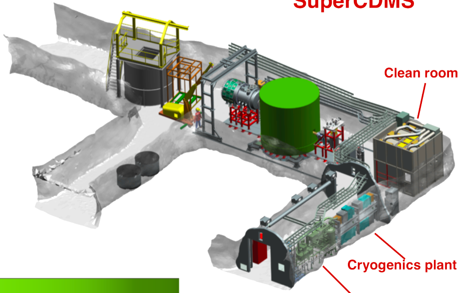
https://supercdms.slac.stanford.edu

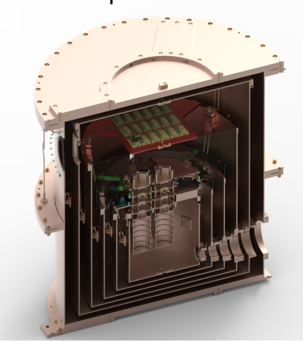


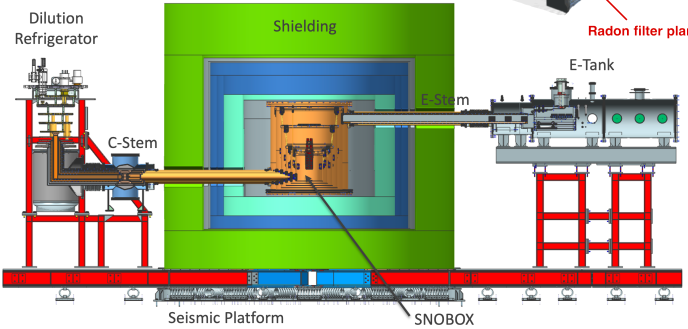
https://www.snolab.ca

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 planned for 2024.
  - More SuperCDMS details in Stefan's preceding talk.

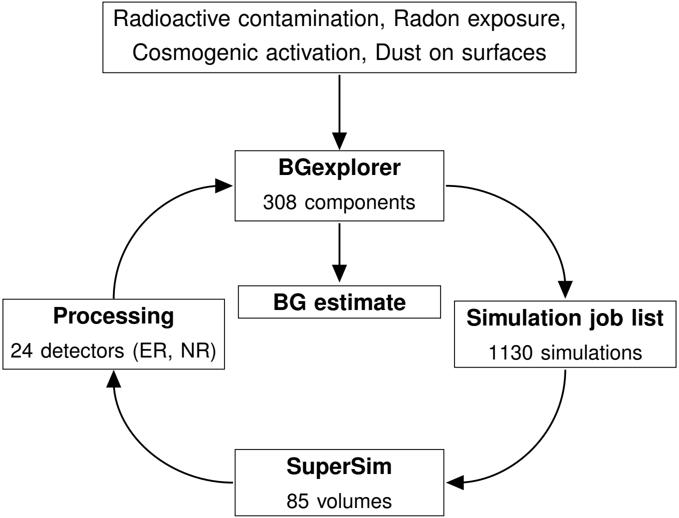




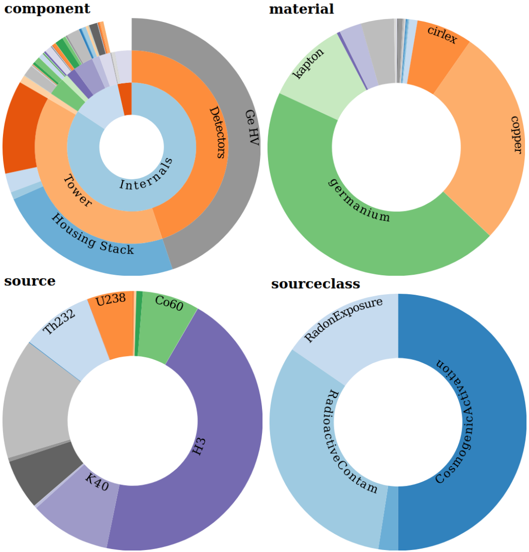


Background simulation campaign for SuperCDMS

- 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.



Background estimate from BGexplorer



https://github.com/bloer/bgexplorer

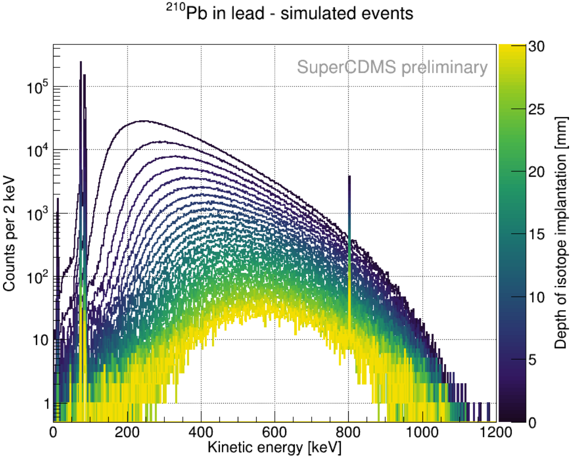
- BGexplorer provides a background estimate based on material assay results.
- Visualizes the BG contribution in pie charts, spectra and tables.
- Enables easy identification of dominating BGs.

SuperCDMS lead shield simulation in SuperSim

- Graded lead shield:
  - Ultra low background (ULB):
    0 - 1 cm – 0.3 Bq/kg
  - Low background (LB):
    1 - 10 cm – 21 Bq/kg
  - Regular background (RB):
    10 - 20 cm – 157 Bq/kg
- Simulating ^{210}Pb in lead shield would consume about 1900 cpu years to achieve sufficient statistics.
  - Simulation procedure needs to be more efficient.

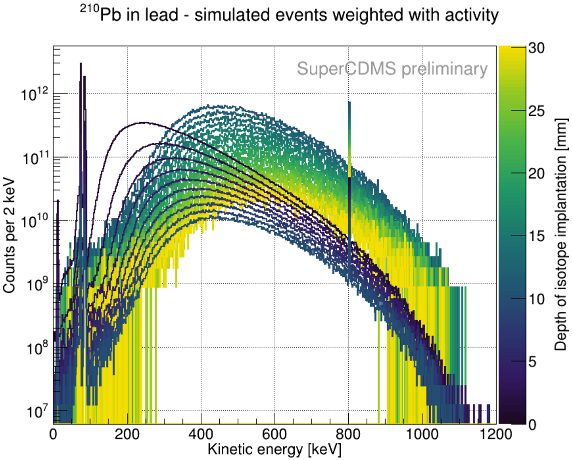
Simulation of ^{210}Pb in lead

- Investigated whether it is sufficient to only simulate ^{210}Pb in the inner 1 cm of lead.
- Simulated ^{210}Pb in various depths from the inner surface of the lead shield and recorded particles leaving it.

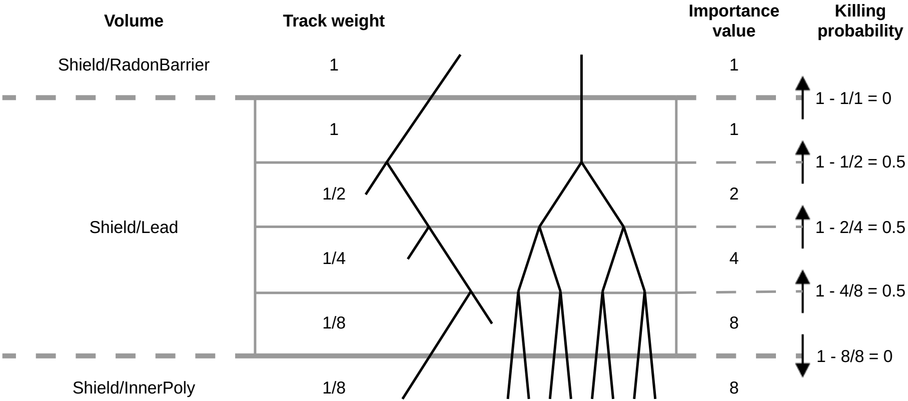


Simulation of ^{210}Pb in lead

- Investigated whether it is sufficient to only simulate ^{210}Pb in the inner 1 cm of lead.
- Simulated ^{210}Pb in various depths from the inner surface of the lead shield and recorded particles leaving it.
- Weighting the spectra with specific activity and mass of the corresponding lead layer shows that the contribution from depths > 1 cm is important.
  - Need a way to propagate particles from the outer lead layers more efficiently.



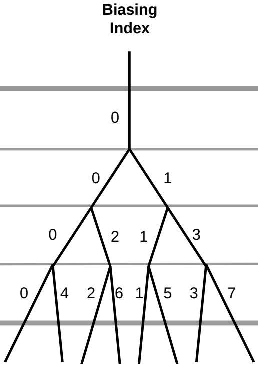
Importance Biasing



- 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.

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 its track weight and the original particle's *Biasing Index*.

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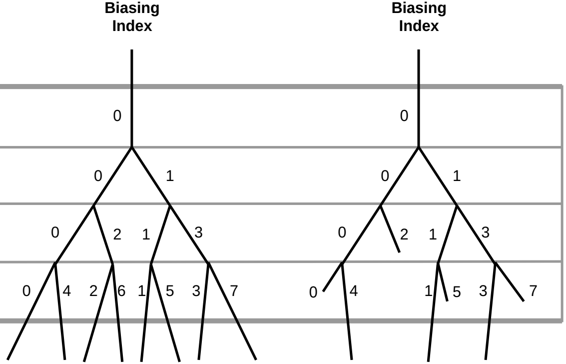
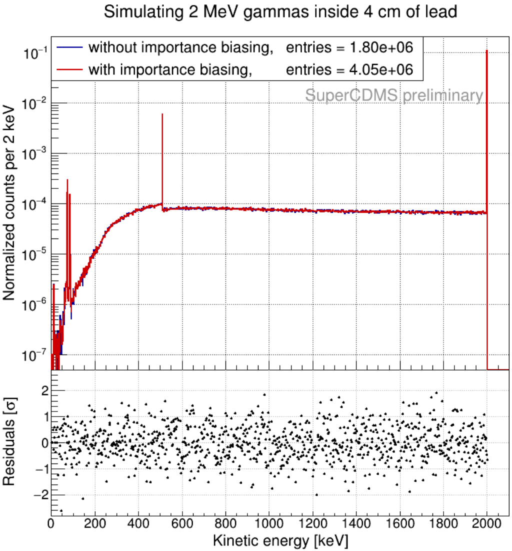


- Distinguish between different split-track topologies within a single generated event.
- The *Biasing Index* of a split particle is increased according to its track weight and the original particle's *Biasing Index*.
- Sum up detector hits for same *Biasing Index* and weight with track weight.

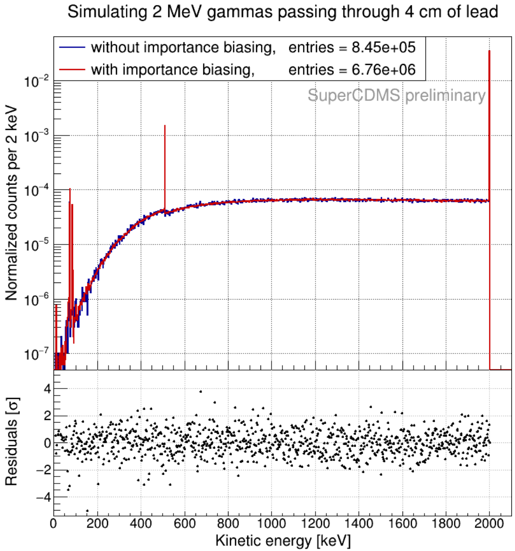
Validation of Importance Biasing and Biasing Index



2 MeV gammas emitted inside the lead shield

- Lead shield thickness shrunk to 4 cm to achieve sufficient statistics without Importance Biasing.
- Record all particle tracks leaving the lead shield.
- Biasing simulation run with 4 importance layers of 1 cm thickness each.

Validation of Importance Biasing and Biasing Index



2 MeV gammas started outside of the lead shield

- Lead shield thickness shrunk to 4 cm to achieve sufficient statistics without Importance Biasing.
- Record all particle tracks leaving the lead shield.
- Biasing simulation run with 4 importance layers of 1 cm thickness each.

Efficiency of Importance Biasing

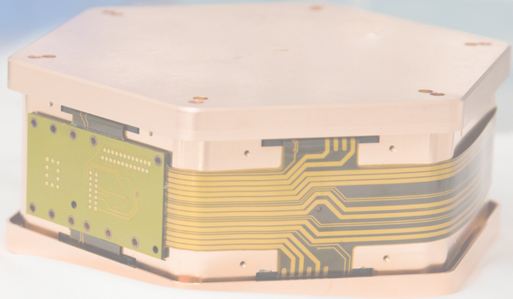
- Count events leaving the lead shield per runtime with and without Importance Biasing.
- Efficiency improvement strongly depends on number and thickness of importance layers.

Lead shield thickness [cm]	Number of Imp. Layers	Events per runtime [1/s] Imp. Bias.	Events per runtime [1/s] no Imp. Bias.	**Efficiency gain**
5.00	4	531.5	108.4	4.9
6.25	5	506.1	62.7	8.1
7.50	6	485.0	35.7	13.6
8.75	7	462.3	20.2	22.9
10.00	8	444.1	11.6	38.4

- 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.
- Studies ongoing to determine optimal importance biasing settings for effective simulations.

Summary & Outlook

- SuperCDMS has a strong background assay program.
- Sufficient statistics are necessary to model the background with simulations.
- Importance biasing improves the simulation efficiency significantly.
- Choice of importance biasing settings depends on multiple parameters.



Flag icons from flaticon.com

SuperCDMS Collaboration

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@SuperCDMS

https://supercdms.slac.stanford.edu

Backup

SuperCDMS' assay types

Radioactive Contamination

- Long-lived radioactive isotopes are contained in traces in all materials.
- Screen each component/material to get the specific activity of the contained radioactive isotopes.

Radon exposure

- Air above surface and underground contains traces of ^{222}Rn, whose decays can implant ^{210}Pb into the surface of exposed materials.
- Need to know the radon level and exposure time to mine air to estimate the decay rate.

Cosmogenic Activation

- Neutrons originating from cosmic showers can activate materials residing on Earth's surface.
- Monitor component's time on Earth's surface and cooldown time until the experiment starts.

Dust on surfaces

- Dust can accumulate on surfaces and can contain radioactive contaminants.
- Need to know the type and concentration of radioactive contaminants, accumulation rate and mass of the dust.