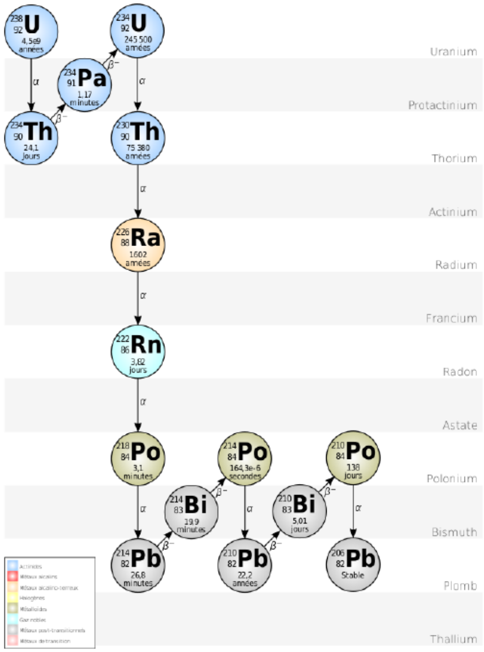
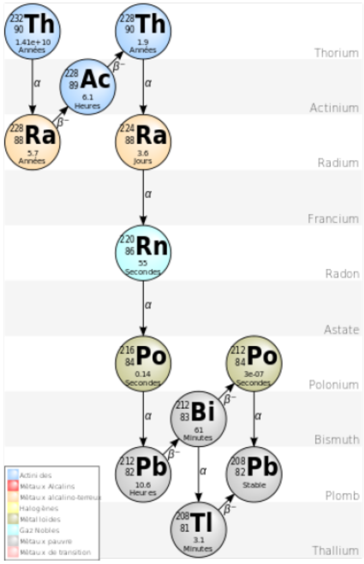
Radon surface contamination

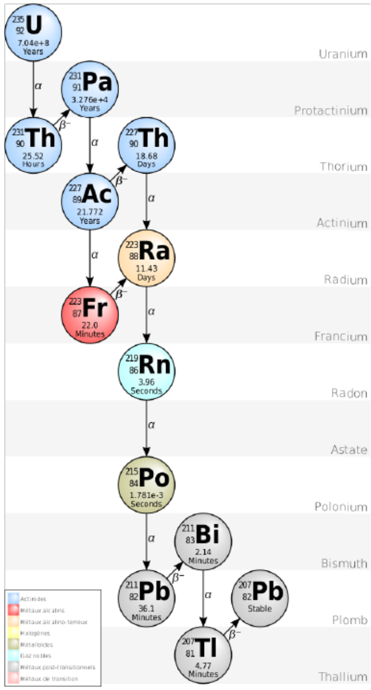
Simulation of implantation depth

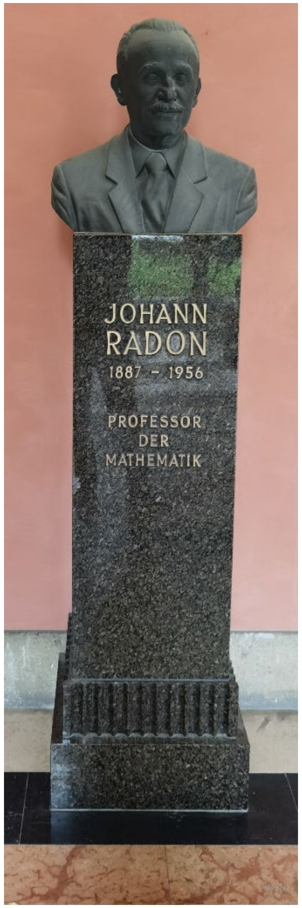
Radon Context

- Radioactive gas emanating from soil, rocks
- It decays and its daughter are contamination source
- Radon is everywhere



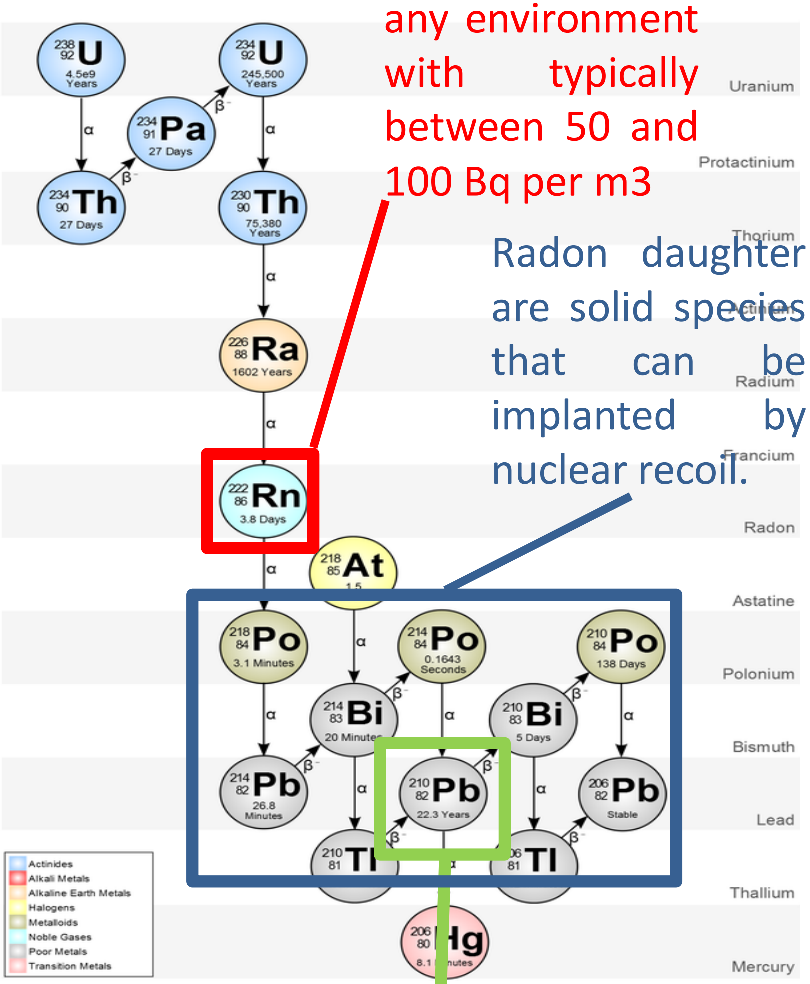






Radon contribution to background

- Gas travelling to the vicinity of the detector
- Radioactive decay produce radiative background
- Nuclear recoil implants radon daughter
- Can happen during whole detector construction



Radon 222 is a gas emanating in any environment with typically between 50 and 100 Bq per m3

Radon daughter are solid species that can be implanted by nuclear recoil.

210 Pb has the longest half life in this part of the chain thus piloting the contamination and its duration

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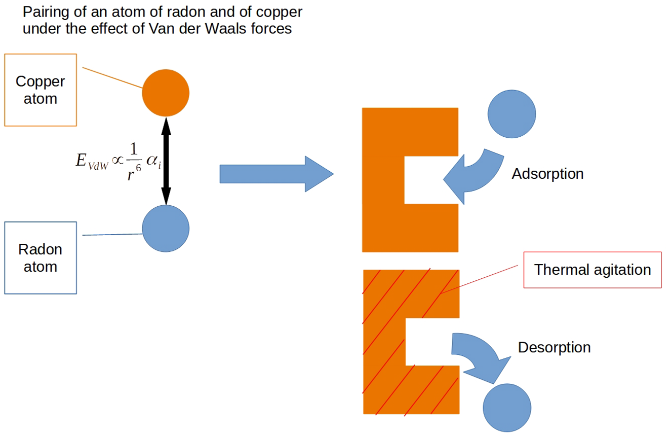
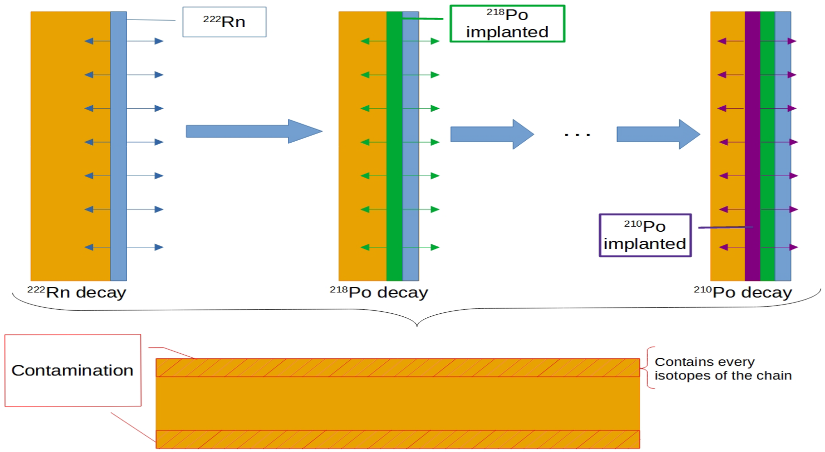
Radon implantation mechanism

- Radon has a probability to adsorb on the surface and then decay on his surface
- The adsorption depends on thermodynamical parameter
- After adsorbtion the radon daughter have a chance to decay and implant 218Po by nuclear recoil, repeat with daughter





Mitigation of radon backgrounds

- During run of low-background experiment radon is flushed away from vicinity of detector typicaly using adsorbtion column
- During construction implantation of radon daughter is accumulating, so surfaces are usually etched to reduce implanted daughter background. Moreover critical pieces need to be transported shielded from radon

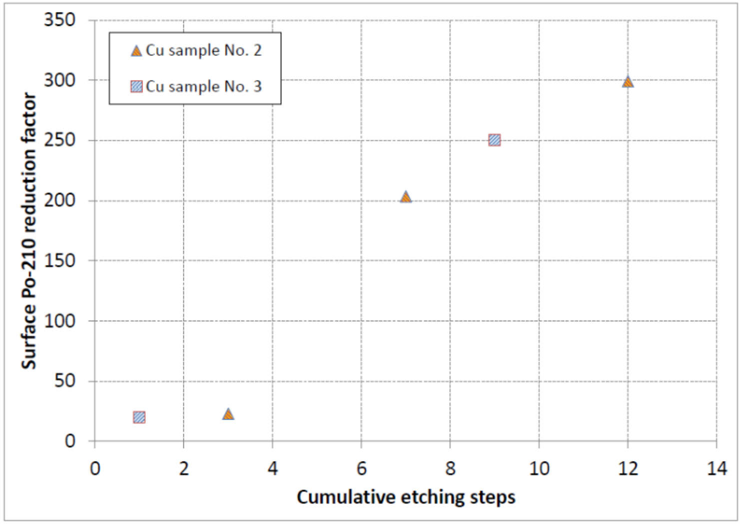
Examples of LSM former radon free air facility

2 x 500 kg charcoal (only one used)
Flux : 150 m3/h air
Activity of ^{222}Rn :
Before facility = 15 Bq/m^3
After facility < 15 mBq/m^3

Implantation removal

- Strategy was usually to etch the copper surfaces with acid mixture (HNO_3/H_2O_2)
- Process has been refined using electrochemical polishing
- Depth up to 100µm are removed
- Contamination removal is probed through 210Po surface activity
- 210Po chemical redeposes after etching

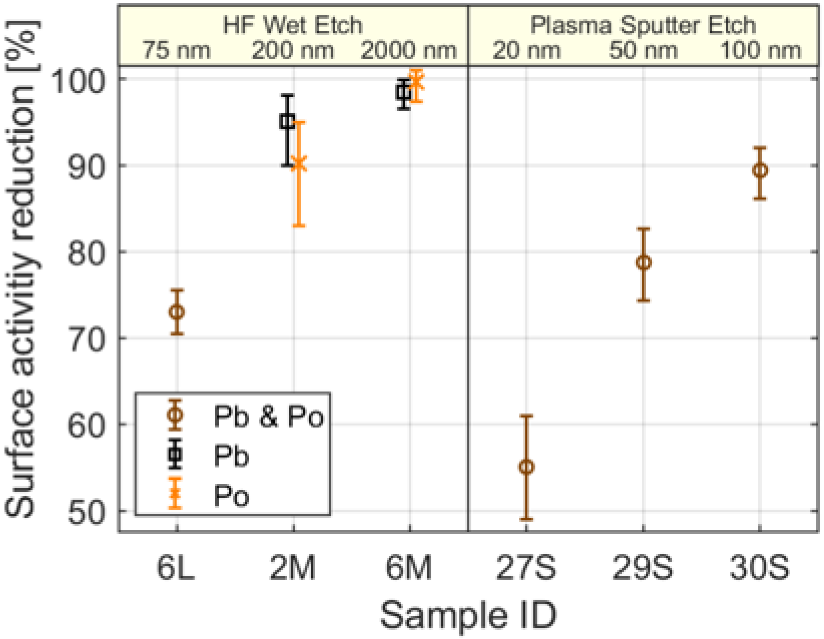
See G. Zuzel, M. Czubak, T. Mróz, M. Wójcik;Institute of Physics Jagiellonian University, Cracow, Poland Low Radioactivity Techniques 2022, 14-17 June 2022, South Dakota Mines / SURF, USA



Implantation removal

- Implantation mechanism comes from nuclear recoil. Available energy ~100keV
- Implantation depth average 50nm and strongly depending on material
- Also backed with non-chemical cleaning techniques

Precision etching was tried on silicon wafer. It showed that main contamination could be removed by only a 100nm. This value is more compatible with the recoil energy as an implantation mechanism



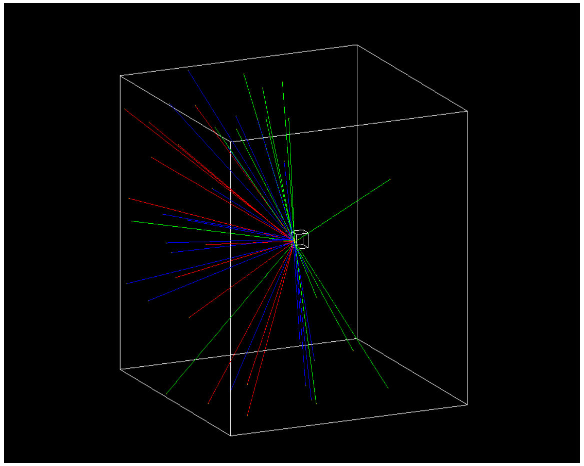
[1] Arnquist, I. J., Bunker, R., Dohnalek, Z., Ma, R., & Uhnak, N. (2023). Exploration of methods to remove implanted 210Pb and 210Po contamination from silicon surfaces. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, *1048*, 168008.

Implantation model

- Implantation modeled through GEANT4
- Use of rdecay package to have the full chain implantation
- Radon position on the surface and full decay monitored
- Altitude 0 on copper plate
- Recorded final step depth

per nucleus

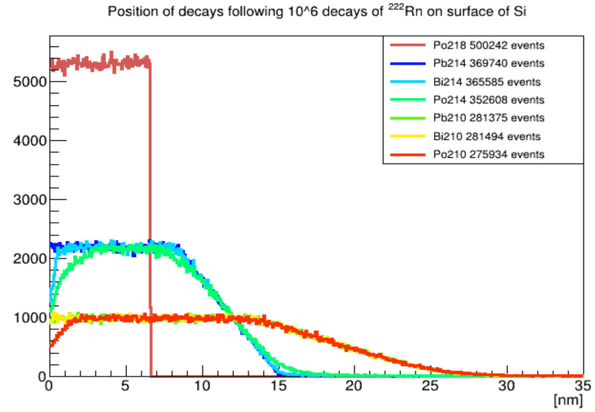
- 1D plot obtained

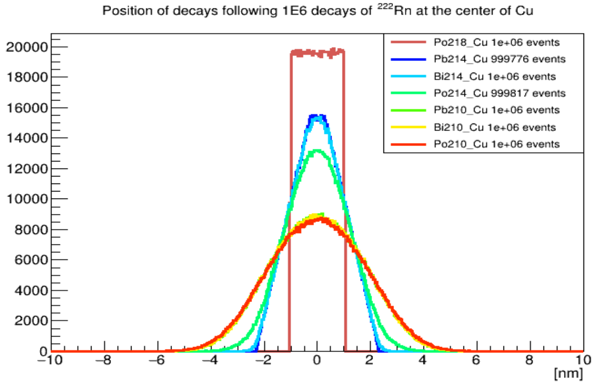


First tests

- Strange shape and non continuous models

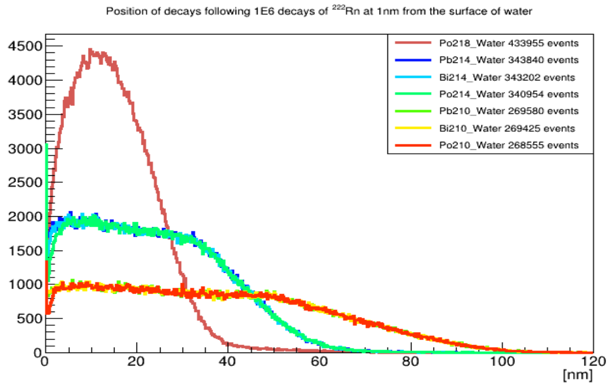
Decay at (0,0,0) and inside the copper plate


Position of decays following 10^6 decays of ^{222}Rn on surface of Si

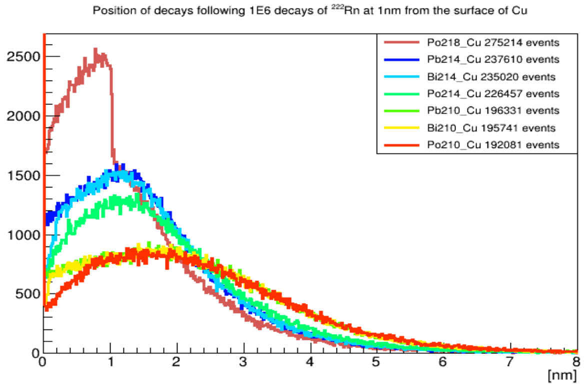

Position of decays following 1E6 decays of ^{222}Rn at the center of Cu

Multiple scattering model (G4UrbanMscModel)

Decays at (0,0,1 nm)


Position of decays following 1E6 decays of ^{222}Rn at 1nm from the surface of water

Coulomb scattering process


Position of decays following 1E6 decays of ^{222}Rn at 1nm from the surface of Cu

The coulomb scattering process produces smoother simulation, is triggered by transportation. It can also be forced by reducing G4step

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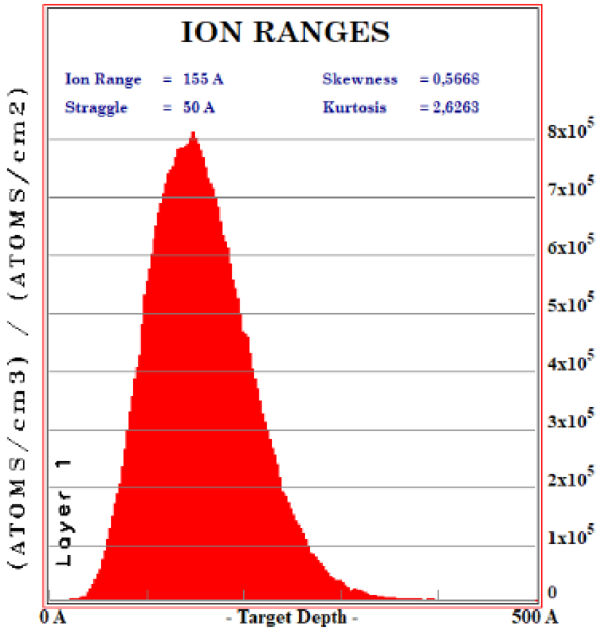
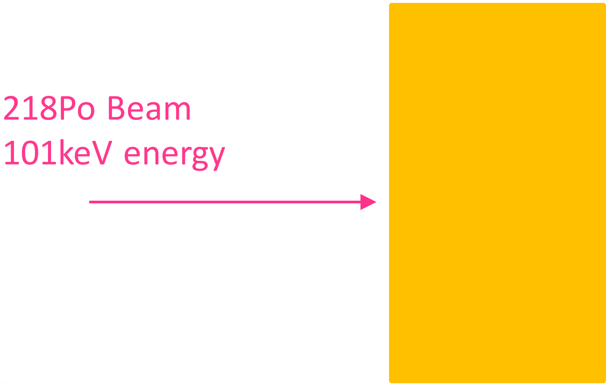
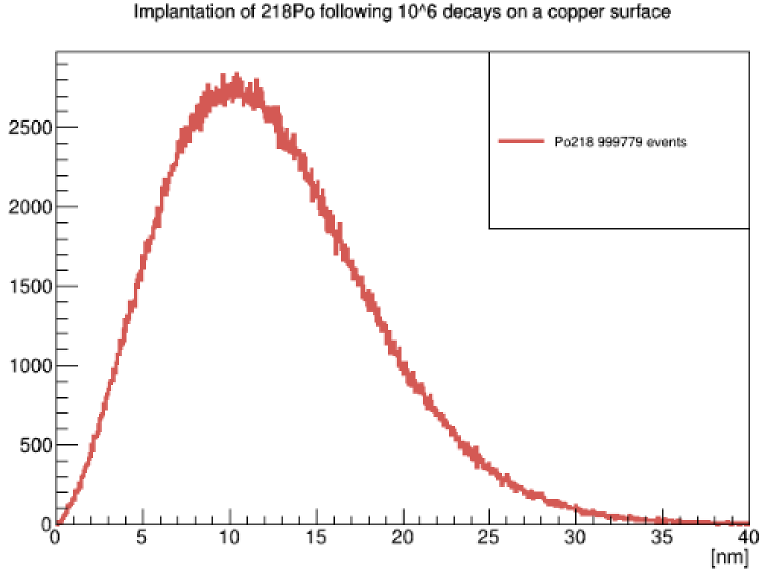
Comparison to SRIM

- SRIM ion is recognized accurate
- Comparizon with rdecay only physics list is dramatic
- Use of StandardNR process to reproduce SRIM







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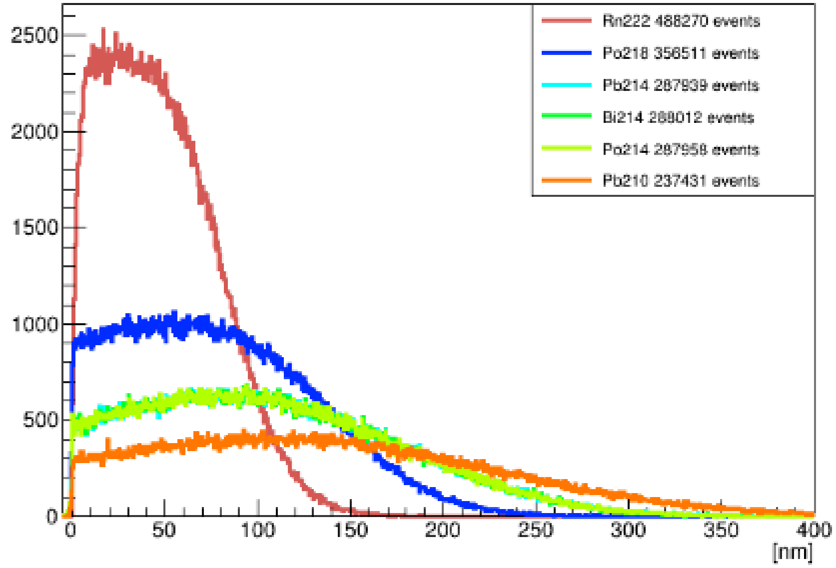
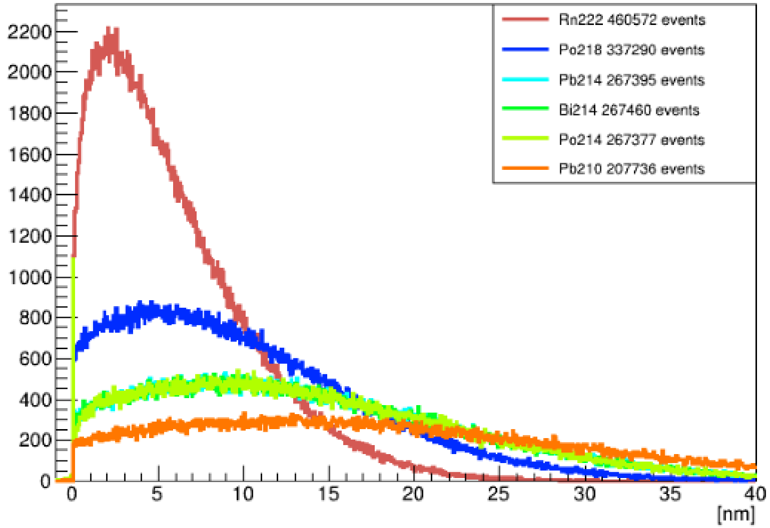
Material contamination

- Different material profiles were tested use this physic list, isotropic decay

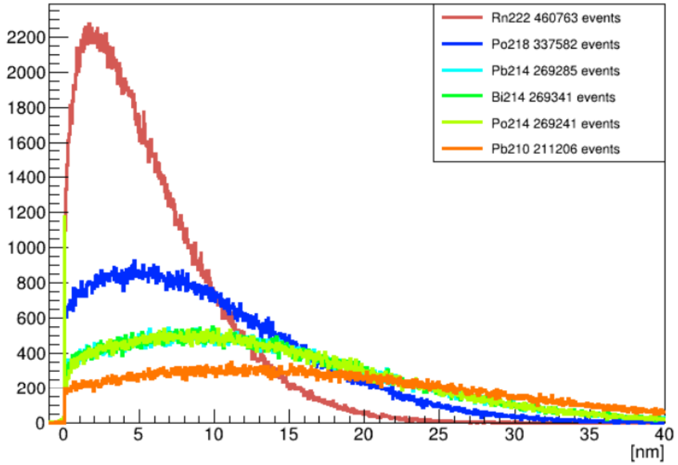
Implantation of 222Rn following 10^6 decays on a polyethylen surface



Implantation of 222Rn following 10^6 decays on a Bronze surface



Implantation of 222Rn following 10^6 decays on a copper surface



Surface modeling

- What was shown before used GEANT4 basic box shape as target
- Reality of surface material is different

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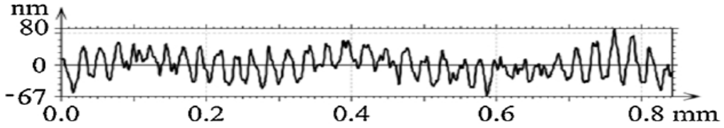
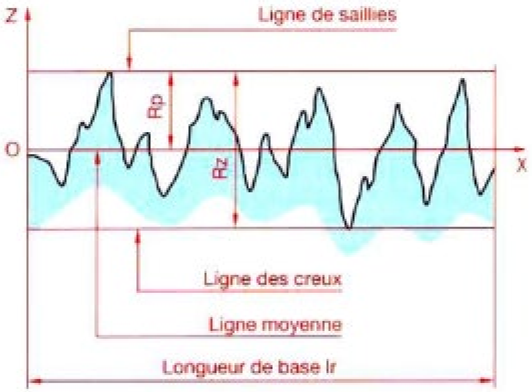


Ra=21 nm, Rt=147 nm

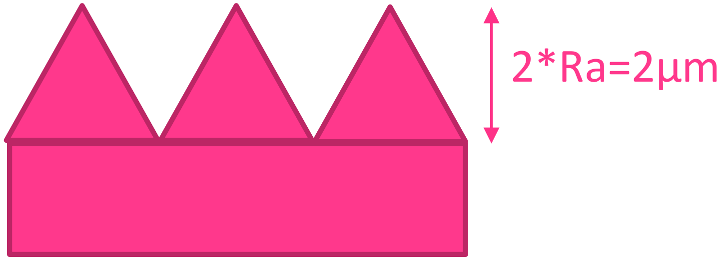
Ra is the mean half peak for a considered surface

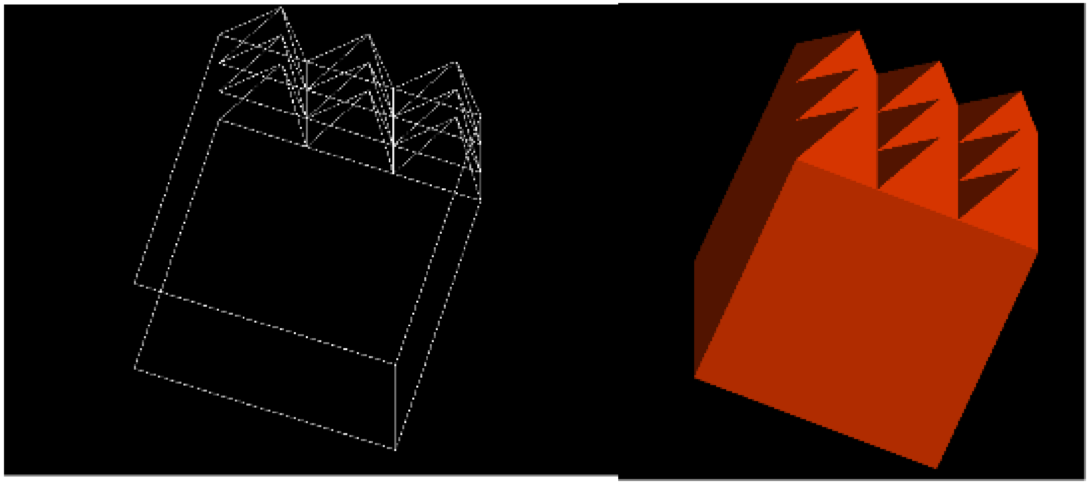
$$Ra = \frac{|z_1|+...+|z_n|}{n}$$



Surface model

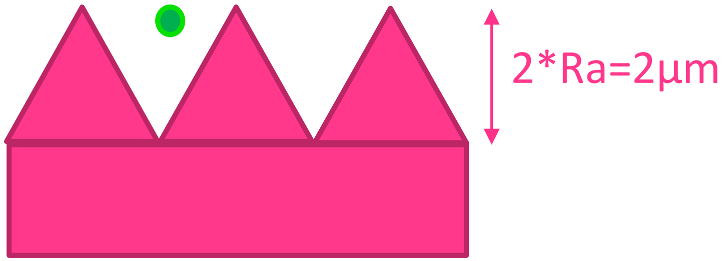
- Surface modeled as 9 pyramids over a cube 20µm



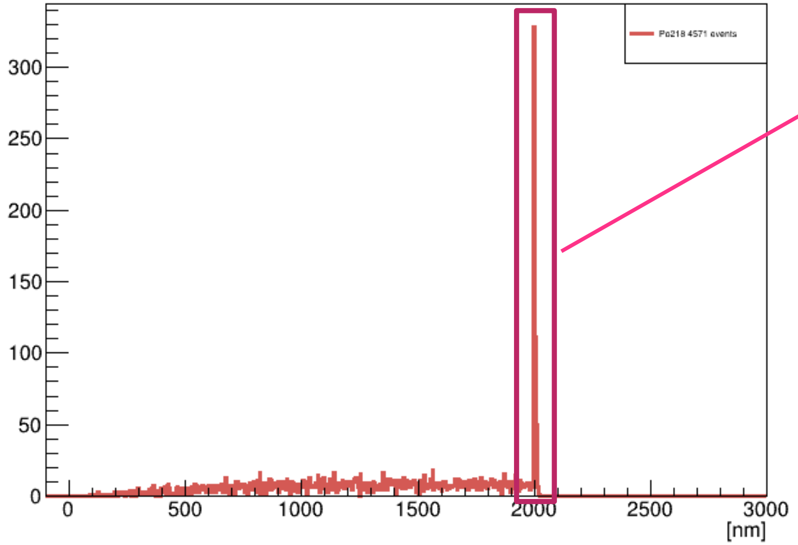


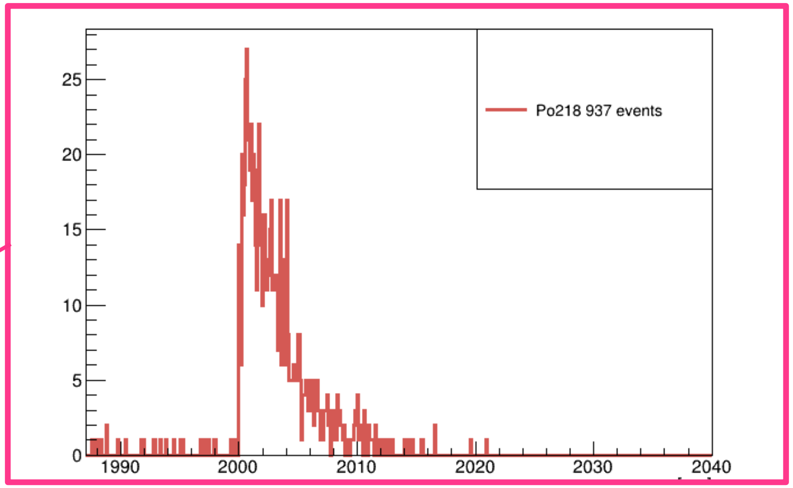
Surface implantation model

Decay : point z=0, iso



Decay of 218 at z=0, between 2 pyramids, implantation depth





Zoom at the bottom of valley

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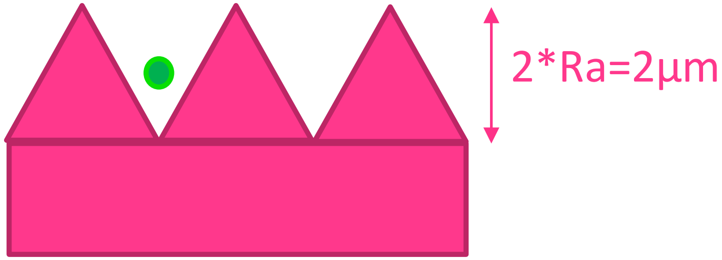
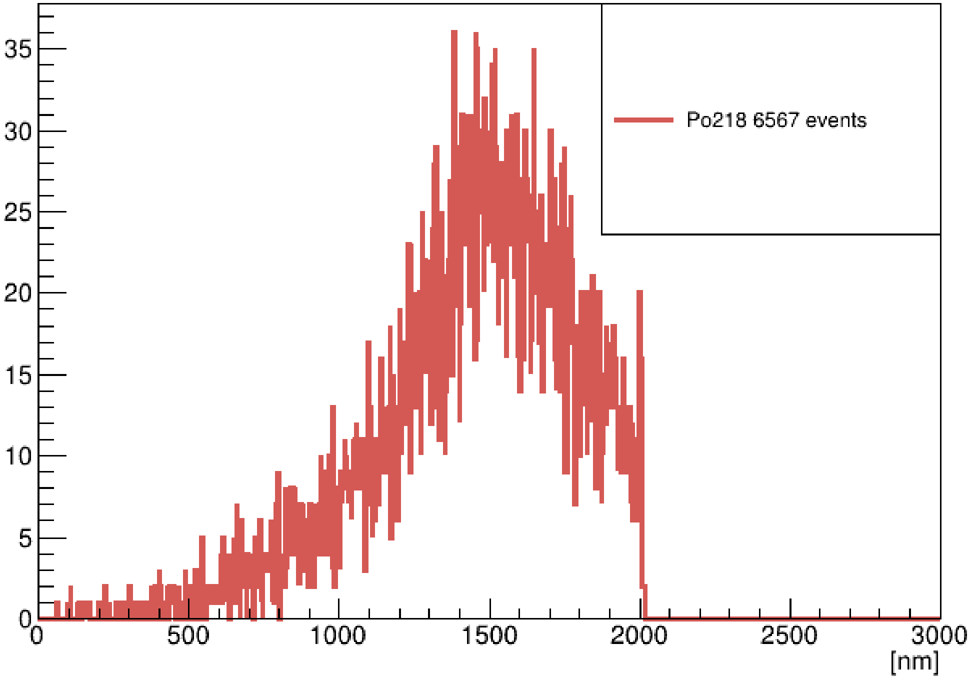
Surface implantation model

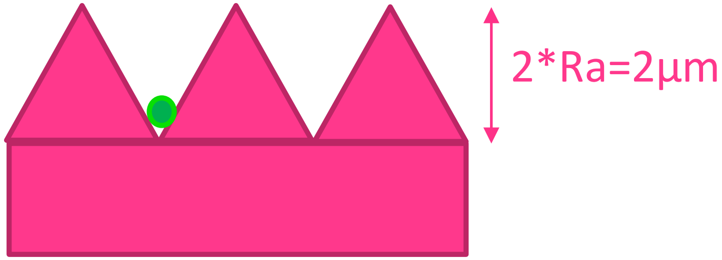
Decay : point z=-1,5, iso

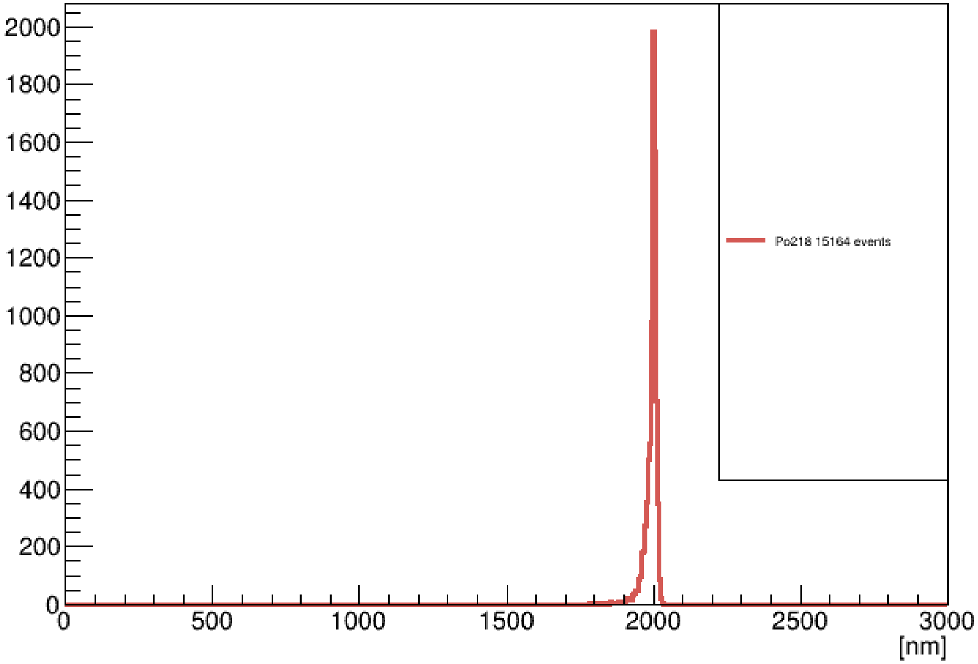




Surface event modeling

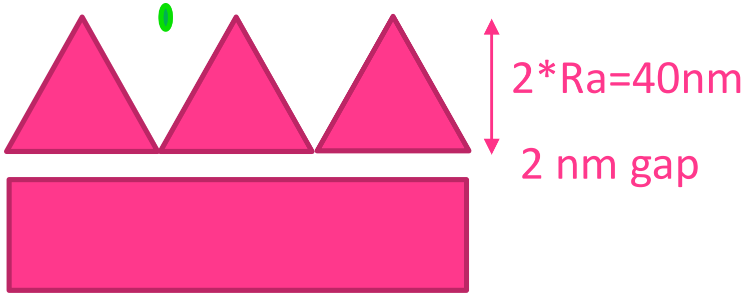
Decay : point z=-1,98, iso





Surface modelling

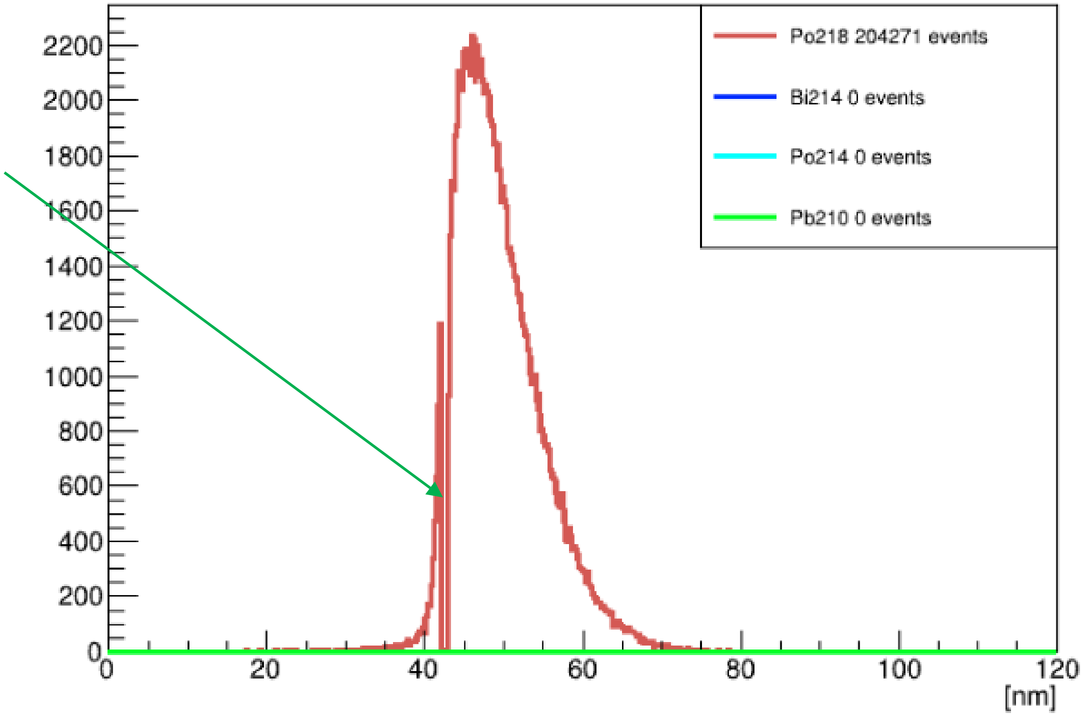
Decay : point z=0, iso



2*Ra=40nm

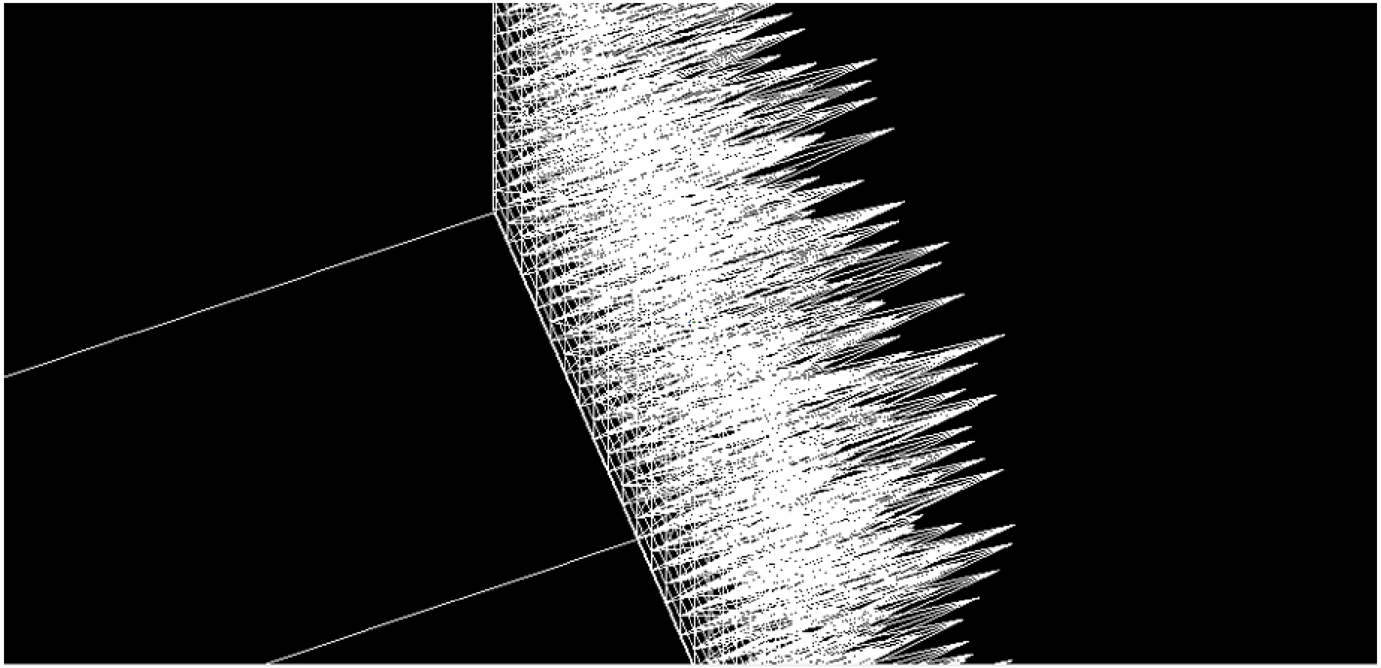
2 nm gap

Gap modelled in the simlation



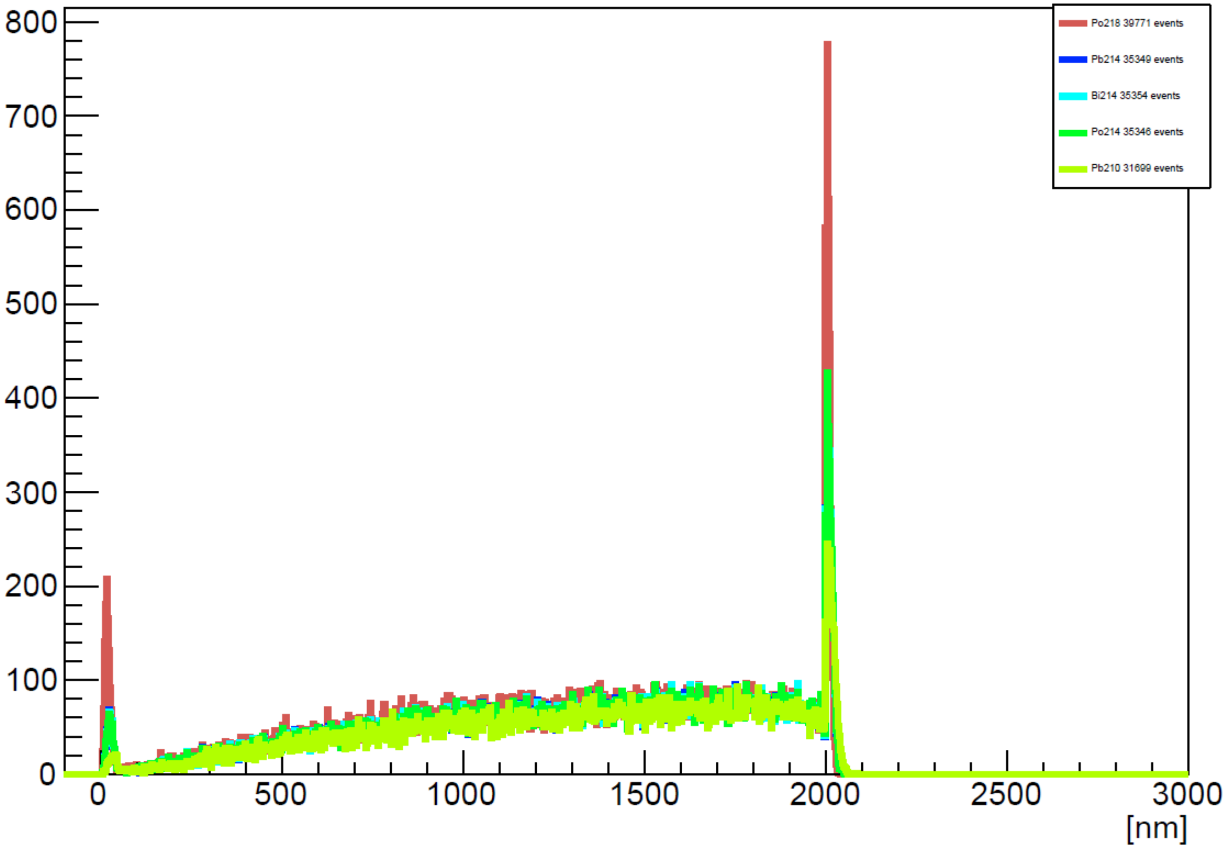
Rugosity approximation

- Pyramids with random heights
- Height randomly distributed between 1 and 5 times 2 um
- 30 by 30 pyramids on plate



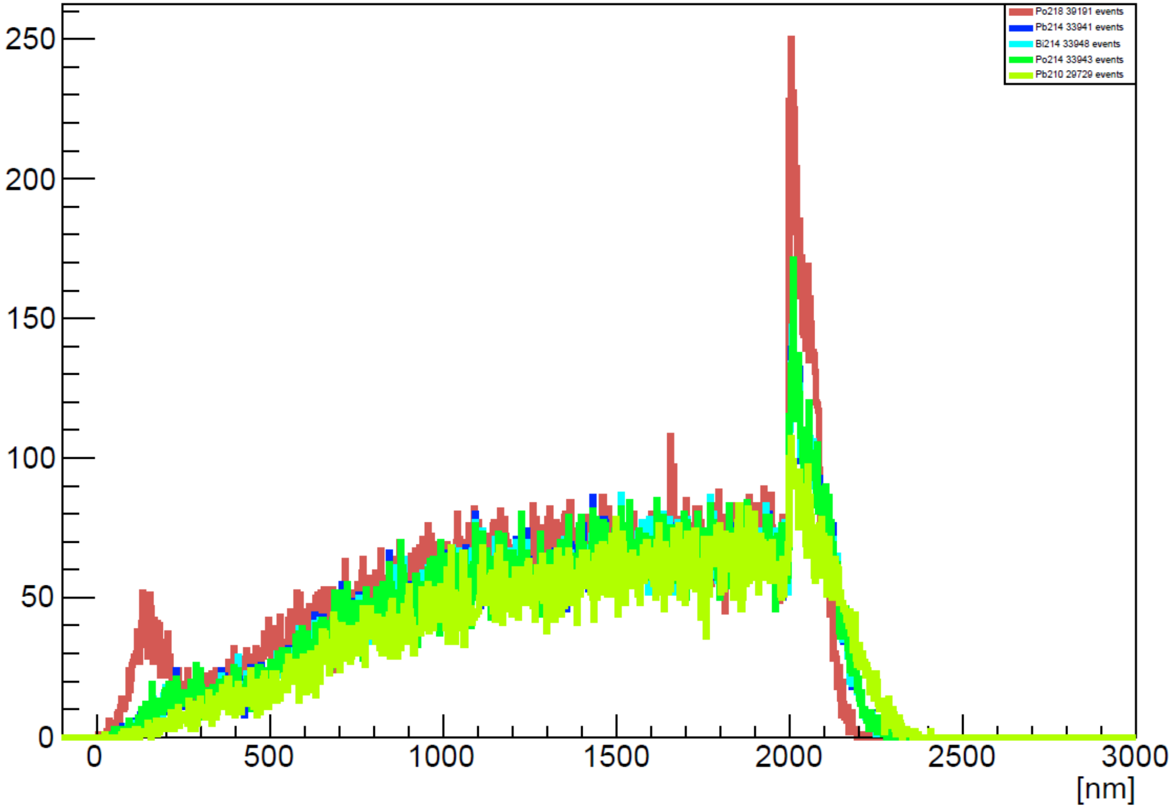
Source shaped as a plate

- Gps/plate 5µm above the top of pyramids
- Display 2 peaks on top of pyramids and in bottoms of valley



Different target

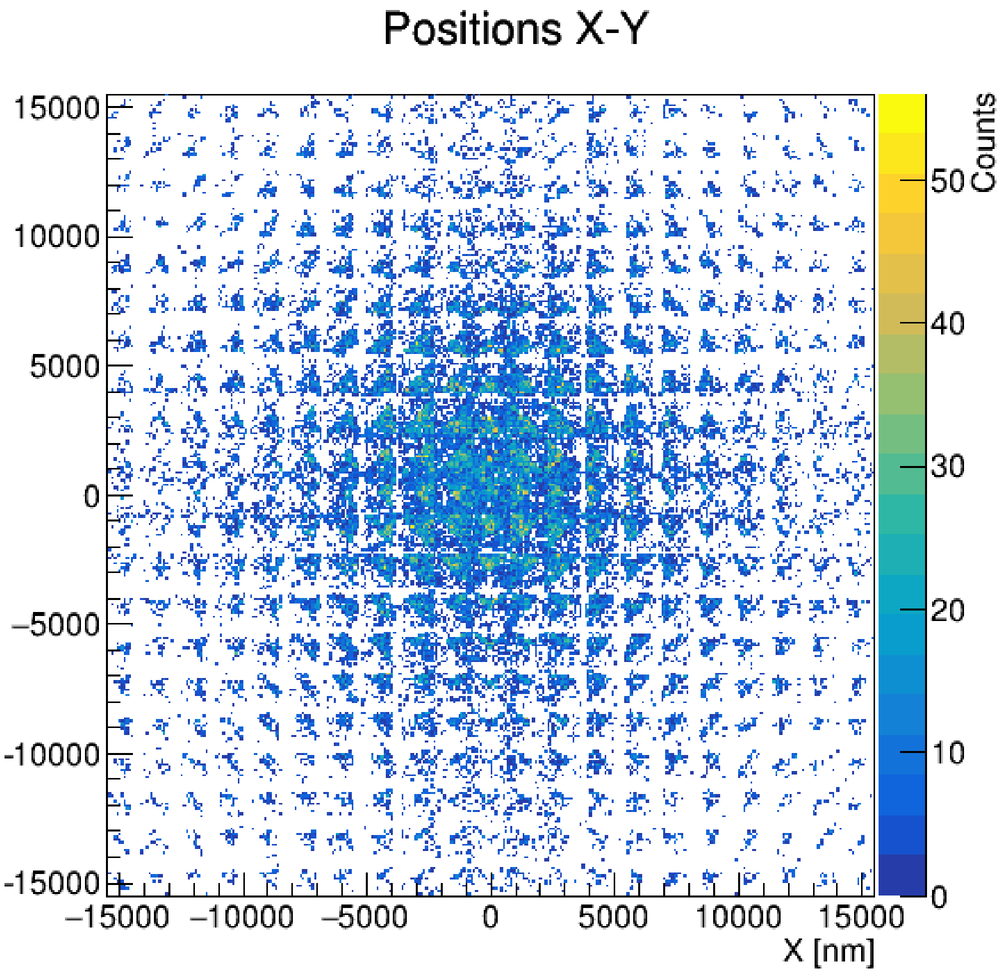
- Material changed to G4Water for influence of Z and density
- Absorption peak wider, pentration length augmented



2D impact of nuclei

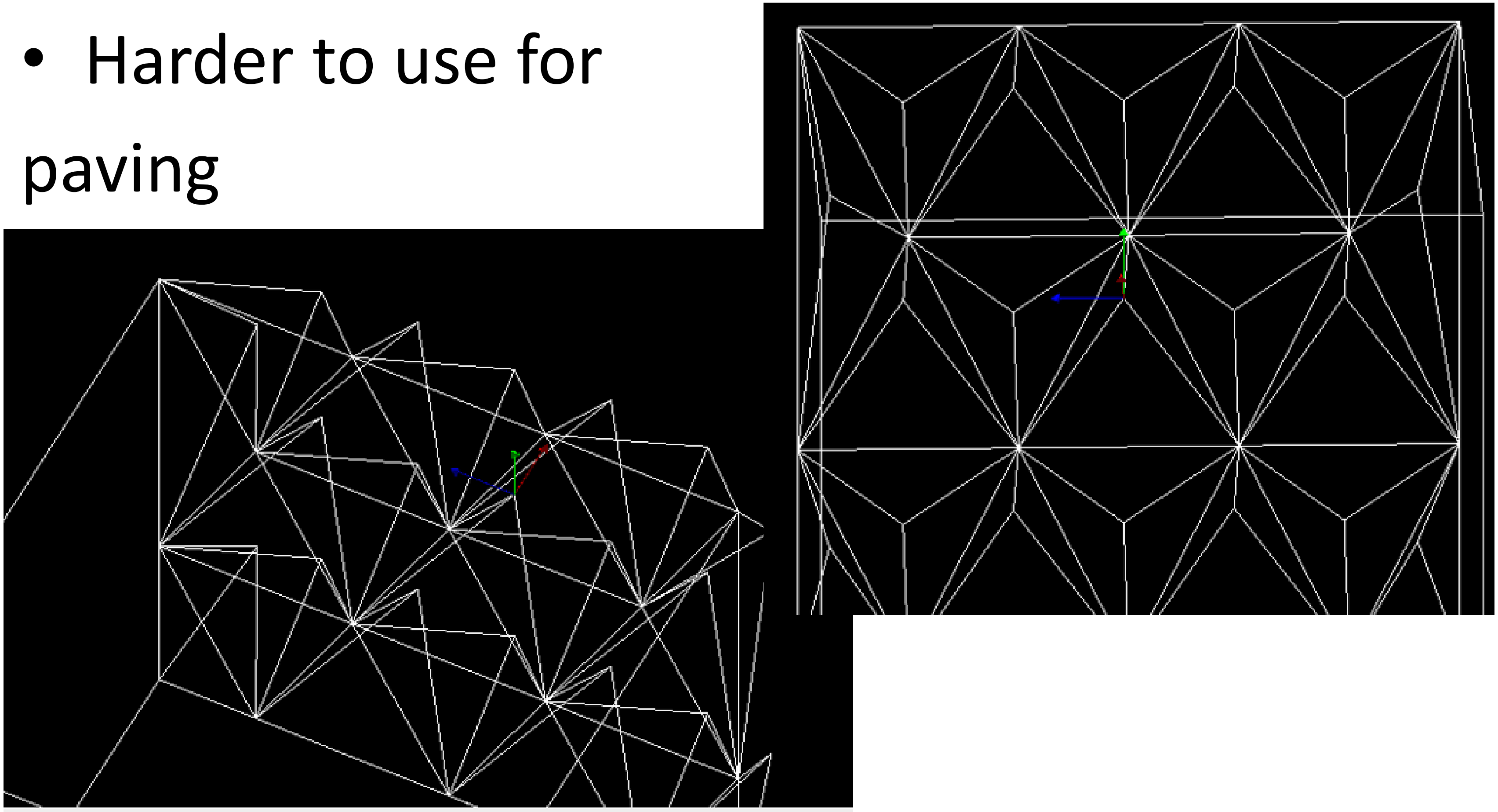
- Implantation of radon daughters cast the shadow of pyramids

Decay point 0 0 0



Other polygon

- No effect on implantation
- Harder to use for paving



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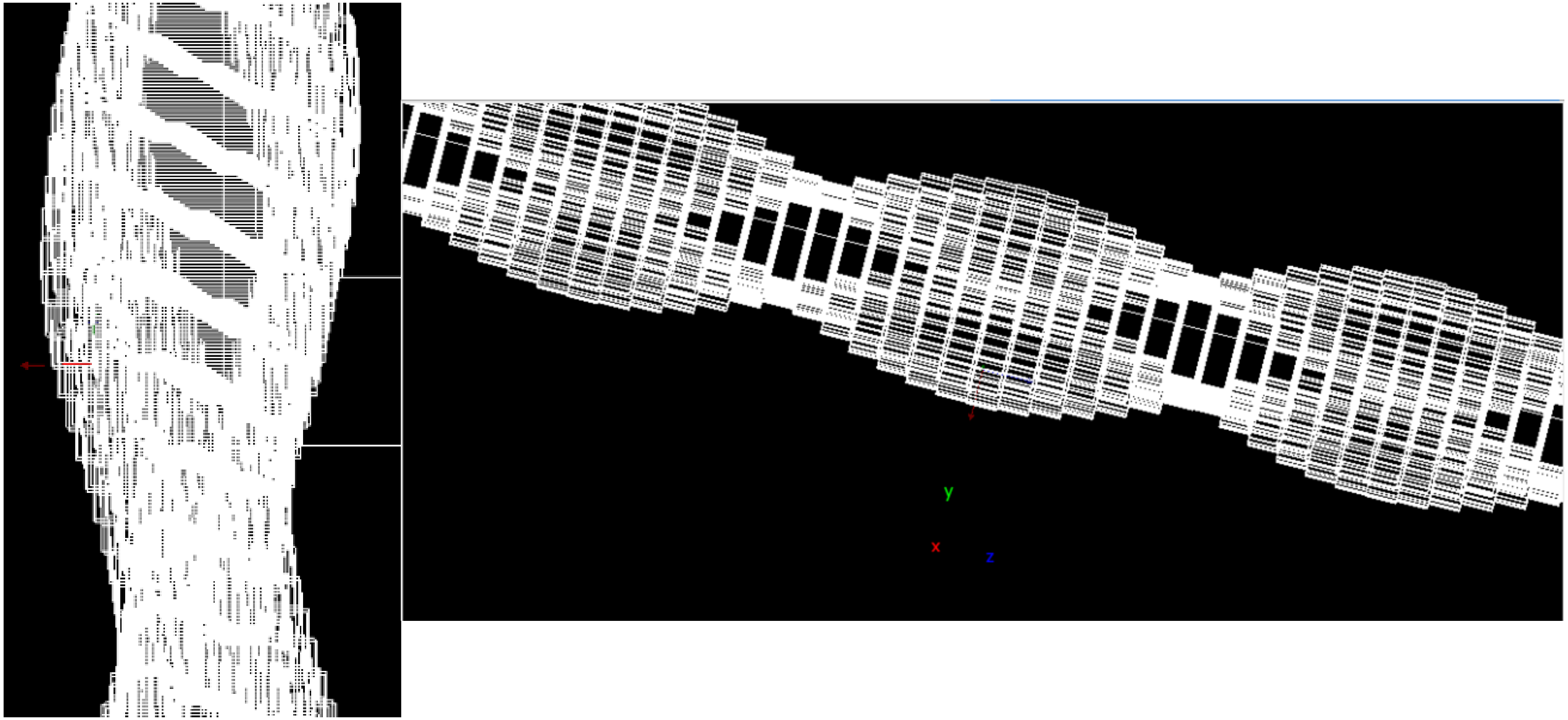
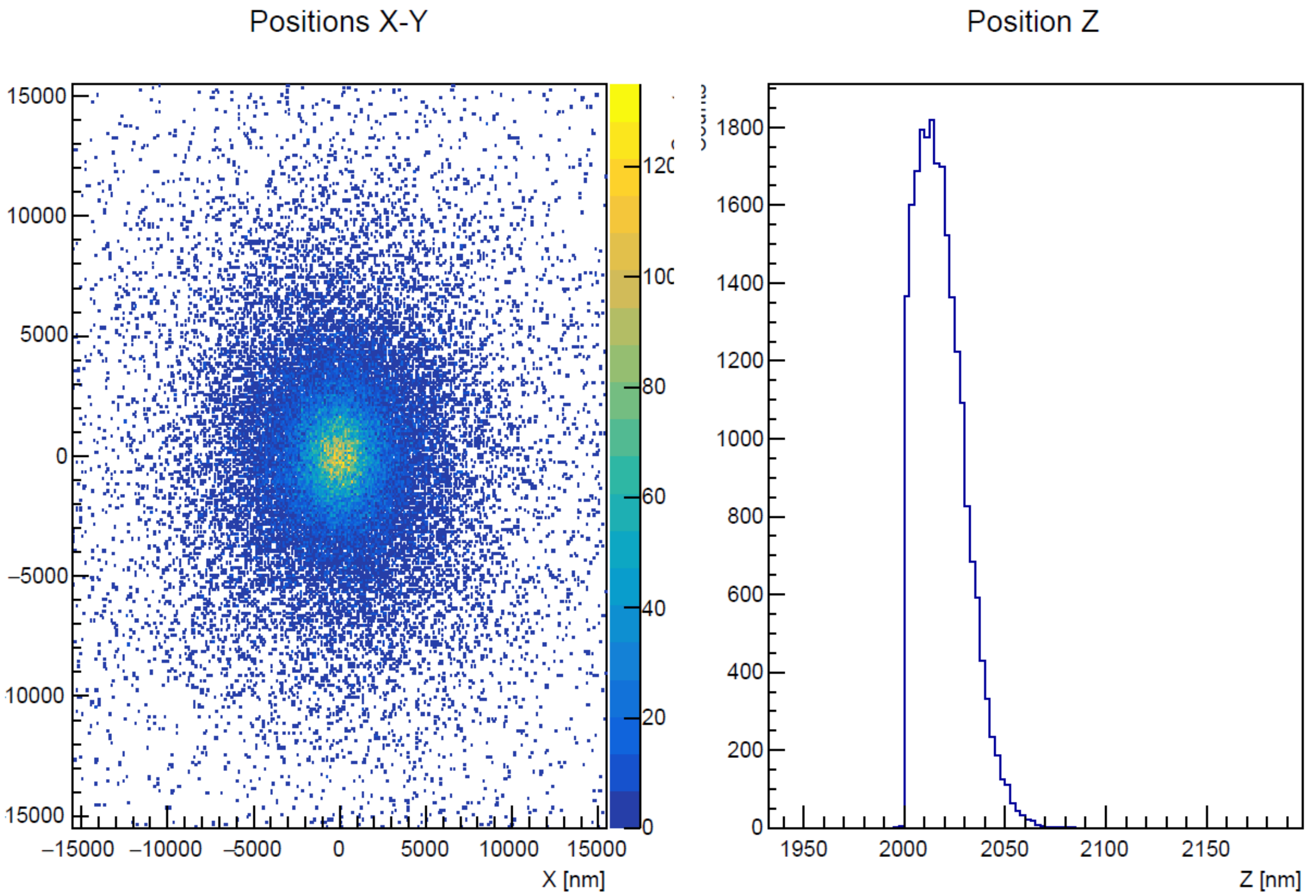
Possibility to model surface with functions

- Height depends on siny and cosx
- Voxel put together to create this geometry



Decay implantation to be crosschecked

- Most ion in the center
- Z implantation around 2 µm



Conclusion

- Debugging work mainly done by Malou Cattaneo
- Additional shaped produced by Antoine Evrard
- Radon implantation background is now a concern for underground experiments
- Simulation of implantation perform with GEANT4 in good agreement with SRIM
- Tools for surface modeling exist, needs to be refined
- Real surfaces to be found in literature and modeled

Conclusion discussion

- Emission of implanted ion should be modeled
- Evidence for 100 nm scale implantation depth rather than µm in simulation!
- Compare with experimental *implantation* in real material at 100 keV scale
- Implantation depth is calculated to be negligible vs rugosity of surface
- Cleaning should be dominated by rugosity removal

Backup 1

- Example of chemical cleaning >10µm
  - Electropolish of Stainless steel: Schnee et al, AIP LRT Conference Proceeding (2013)
  - Cu etching and electroplating: Bunker et al, NIM A, 2020
  - Polymers (PTFE) Leaching: Bruenner et al, Eur Phys. J. 2021
  - Metals (Cu, SS, Ge) etching and electropolishing: Zuzel et al, AIP LRT Conference Proceeding (2018)
  - Silicon crystal sidewall etching: Street et al, NIM A, 2020

GEANT4 Config

- Geant 4 10.7 p2 from CENBG VM package
- Physics list StandardNR from example TestEm7
- Mendenhall, M. H., & Weller, R. A. (2005). An algorithm for computing screened Coulomb scattering in Geant4. *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, 227*(3), 420-430.