PICO40L Geant4 neutron background simulations

Arthur Plante and Chen Wen Chao

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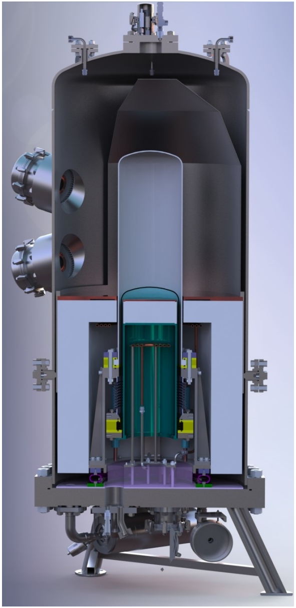
Outline

- Neutrons are one of the main background for dark matter searches with bubble chambers
- Knowledge on neutron production mechanism is required
- Complete detector simulations must be performed to predict the number of single/multiple bubble events generated by neutrons

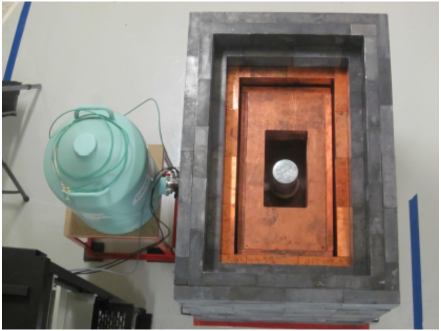
PICO40L

Detector characteristics

- C_3F_8 bubble chamber containing 40L of active volume
- Pressure vessel increased diameter (24 inches PICO60 vs 36 inches PICO40L)
- Component with high concentration of contaminants moved further away from active liquid → lower background
- Rightside up design removes possible issues with water identified in the past.
- Top section is hot (15°) and bottom section is cold (-25°).
- Freon in contact with bellows is cold → no bubbles.



Backgrounds



- Alpha background→ Acoustic discrimination
- Gamma background → 10^{-10} rejection at 3.3 keV
- Neutron background→ Two production mechanisms:
  - Muon induced neutron interacting with the rock
  - Neutrons produced by intrinsic contamination of the components by ^{238}U,^{235}U and ^{232}Th

Geant4 simulations performed to:

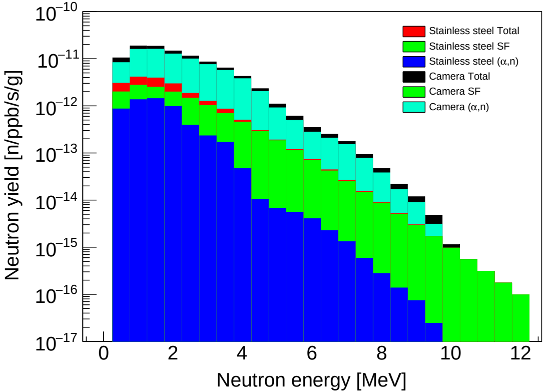
- Predict # of single and multiple bubble events produced by neutrons due to the contamination of ^{238}U,^{235}U and ^{232}Th

Neutron energy spectrum and fluence

Processes

Neutrons are produced via 3 different processes:

- Spontaneous fission
- Delayed neutrons following fission
- $(\alpha$,n) reactions



To decrease fluence:

- Select material of components (lower A $\rightarrow$ higher neutron yield)
- Select materials with low contamination levels (https://www.snolab.ca/users/services/gamma-assay/ and https://www.radiopurity.org/)

- Use GDML(Geometry Description Markup Language) for PICO40L geometry
- Use McCad to translate STEP file into GDML format
- McCad can also translate STEP file into MCNP
- Automated geometry production
- Starting from SLDWorks file the PICO40L geometry can be build within a day.

Why use GDML?

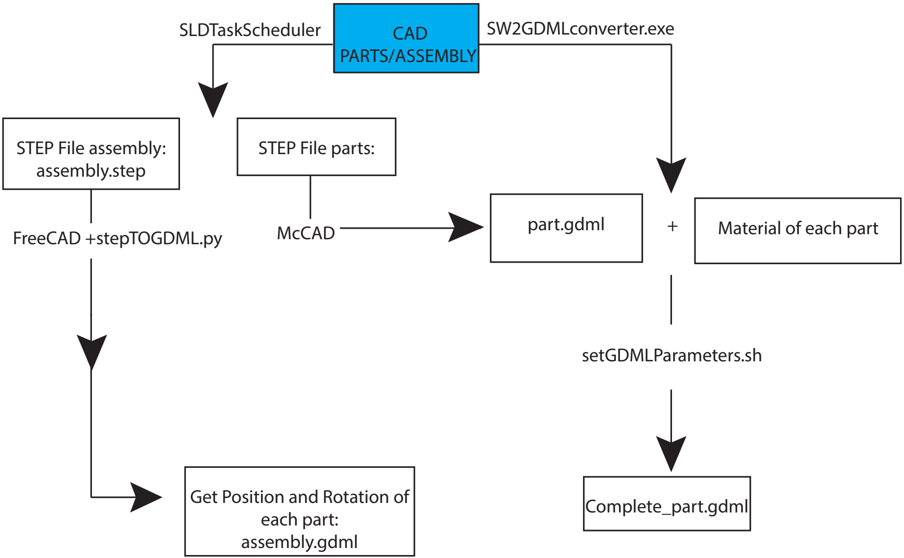
- GDML is based on XML (Extensible Markup Language)$\rightarrow$ Simple, easy to read and modular!
- GDML is application independent $\rightarrow$ Compatible with Geant4, McCAD and ROOT!

Why use McCAD?

- McCAD can decompose (more precise). It does not approximate !
- Files are smaller than approximating methods $\rightarrow$ faster!
- Can translate STEP files into both MCNP and Geant4 $\rightarrow$ Direct comparison possible (not tested yet)
- Made it possible to have automated geometry production $\rightarrow$ Remove possible human errors when writting components and their positionning.
- Much faster to produce geometries

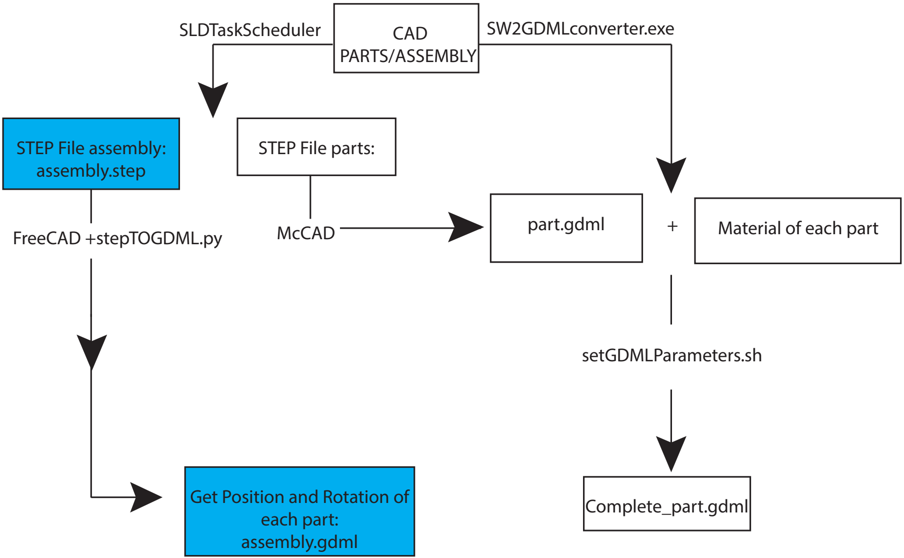
SolidWorks to GDML

Block diagram



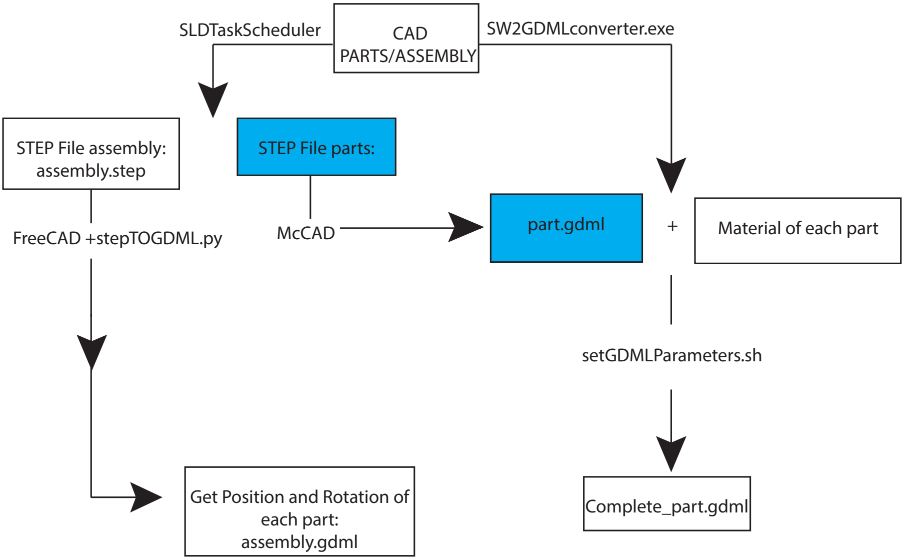
SolidWorks to GDML

Block diagram



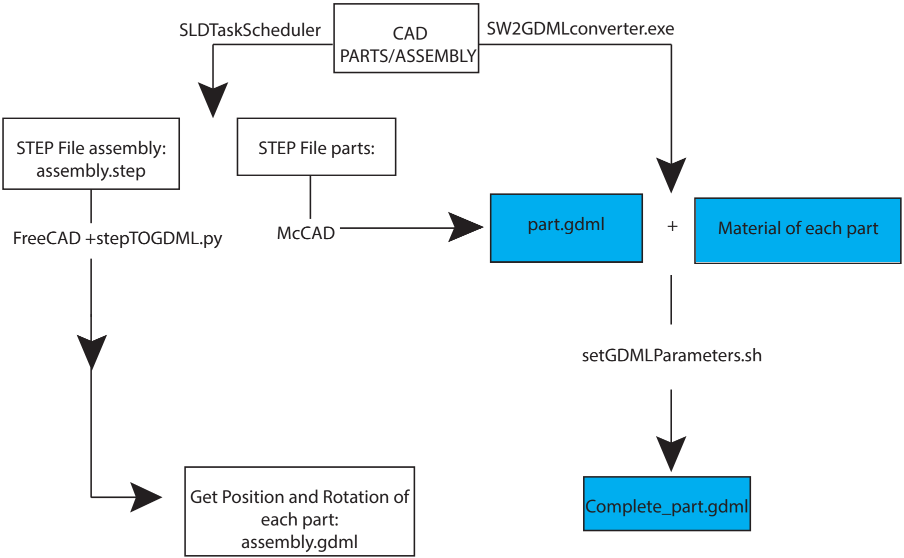
SolidWorks to GDML

Block diagram



SolidWorks to GDML

Block diagram



Several factors can increase neutron background:

- Close to the active volume:
    - Titanium flanges + o-rings (NBR) + spacers (PTFE)
    - Bellows and their flanges (SS)
    - Quartz vessel
    - Copper heating plates
    - Piezo-electric sensors
    - Mineral oil
- Massive components
    - Pressure vessel
    - Mineral oil
- High neutron yield
    - Cameras
    - Lenses
    - Retroreflector

Pressure vessel Internals

Geant4 simulation

Some preliminary numbers

Components	PICO40L Leakage probability singles(multiples)$\times 10^{-4}$	PICO60 Leakage probability singles(multiples)$\times 10^{-4}$
Quartz jar	800(2500)	788(2300)
Camera	0.62(2.2)	10(29)
Retro reflector	2.5(8.5)	86(222)
Pressure vessel	0.056(0.19)	6.8(19)

- Leakage probability = Bubbles / simulated neutrons
- Compares only geometrical features
- Does not take into account decreases in contamination levels
- Does not take into account mass of the components

Conclusion

- PICO40L neutron background prediction is lower than PICO60
- McCAD is really useful; great for large amount of simple geometries.
- Limitations: Conical shapes and torus and other complex geometries.
- Good news: people are still working on improving McCAD and we are in contact with them.
- Need to start working on translation of STEP file to MCNP
- Package available in a docker container soon
- Will be released on GitHub in near future
- Contact me: plante@lps.umontreal.ca or Chen: chen@lps.umontreal.ca

Conclusion

Neutron energy spectrum and fluence

SOURCES4C

Neutrons energy spectrum and fluence is calculated with SOURCES4C

Inputs:

- Atomic fraction of the material
- Decay chain of contaminant (^{238}U,^{235}U,^{232}Th)
- Isotopic content of elements present in the material

Outputs:

- Neutron yield of the different processes (n/s/ppb/g)
- Neutron energy spectrum (required for simulations)

Limitations:

- Neutron energy spectrum is not precise (0.5 MeV bins)
- Does not contains a full library of the cross section.
- In the future : Neucbot!