PICO40L Geant4 neutron background simulations

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Outline

1. Introduction
2. PICO40L detector overview
3. Neutron background
4. Geant4 geometry and simulations
Motivations

- 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
C$_3$F$_8$ 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 $\rightarrow$ lower background

Rightside up design removes possible issues with water identified in the past.

Top section is hot ($15^\circ$) and bottom section is cold (-25$^\circ$).

Freon in contact with bellows is cold $\rightarrow$ 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 $^{238}\text{U}$, $^{235}\text{U}$ and $^{232}\text{Th}$

Geant4 simulations performed to:
- Predict # of single and multiple bubble events produced by neutrons due to the contamination of $^{238}\text{U}$, $^{235}\text{U}$ and $^{232}\text{Th}$
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/)
SolidWorks to gdlm

PICO40L simulations

- 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.
SolidWorks to GDML
GDML and McCAD

Why use GDML?
- GDML is based on XML (Extensible Markup Language) → Simple, easy to read and modular!
- GDML is application independent → Compatible with Geant4, McCAD and ROOT!

Why use McCAD?
- McCAD can decompose (more precise). It does not approximate!
- Files are smaller than approximating methods → faster!
- Can translate STEP files into both MCNP and Geant4 → Direct comparison possible (not tested yet)
- Made it possible to have automated geometry production → Remove possible human errors when writing components and their positioning.
- Much faster to produce geometries
SolidWorks to GDML

Block diagram

- SLDTaskScheduler
- CAD
- PARTS/ASSEMBLY
- SW2GDMLconverter.exe

- STEP File assembly: assembly.step
- FreeCAD + stepTOGDML.py

- STEP File parts:
- McCAD

- part.gdml
- + Material of each part

- Get Position and Rotation of each part: assembly.gdml

- setGDMLParameters.sh

- Complete_part.gdml
SolidWorks to GDML

Block diagram

- **STEP File assembly**: `assembly.step`
- **STEP File parts**: `part.gdml`
- **Material of each part**
- **Get Position and Rotation of each part**: `assembly.gdml`
- **Complete_part.gdml**

Flow:

1. **SLDTaskScheduler**
2. **CAD PARTS/ASSEMBLY**
3. **SW2GDMLconverter.exe**
4. **FreeCAD +stepTOGDML.py**
5. **McCAD**
6. **Get Position and Rotation of each part**
7. **setGDMLParameters.sh**
8. **Complete_part.gdml**
SolidWorks to GDML

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SolidWorks to GDML
Block diagram

SLDTaskScheduler

CAD
PARTS/ASSEMBLY

SW2GDMLconverter.exe

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FreeCAD +stepTOGDML.py

STEP File parts:
McCAD

part.gdml + Material of each part

Get Position and Rotation of each part: assembly.gdml

setGDMLParameters.sh

Complete_part.gdml
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
Geant4 simulation
Some preliminary numbers

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

- Leakage probability $= \frac{Bubbles}{simulated$ 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
THANK YOU!

Questions?
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!