Exploring Geant4 Performance in Optical Processes

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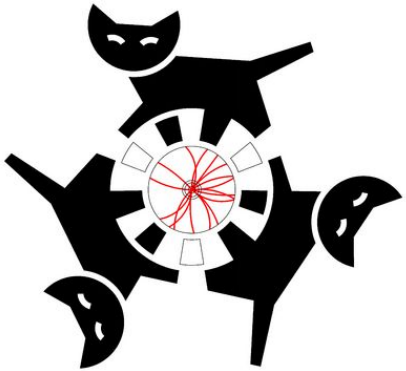
Geant4: Introduction

- Geant4 is a toolkit for the simulation of the passage of particles through matter.
  - Geant4 is a very flexible toolkit, allowing the creation of very simple to extremely complex applications.

- CaTS(Calorimetry and Tracker Simulation) is a framework based on Geant4. Used for example: Calorimetry and Tracking detectors.
  - Developed by Hans Wenzel



Optical Physics

- Optical properties are part of the material properties in the GDML file. They have to be provided by the user before Scintillation and Ĉerenkov processes can work.
  - **Indices of refraction**

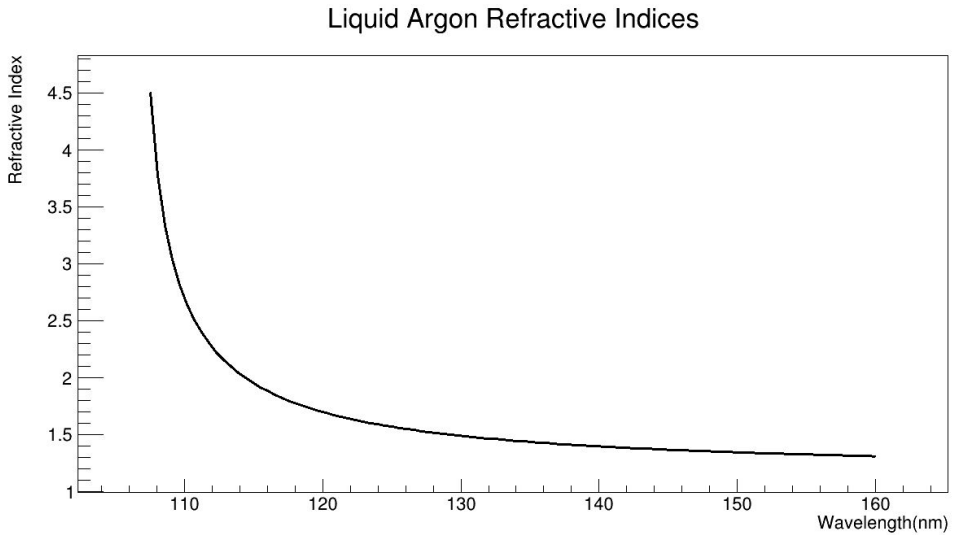
Sellmeier Equation for LAr

$$n^2 = a_0 + \frac{a_{UV}\lambda^2}{\lambda^2 - \lambda_{UV}^2} + \frac{a_{IR}\lambda^2}{\lambda^2 - \lambda_{IR}^2}$$

Generate indices

Into GDML file

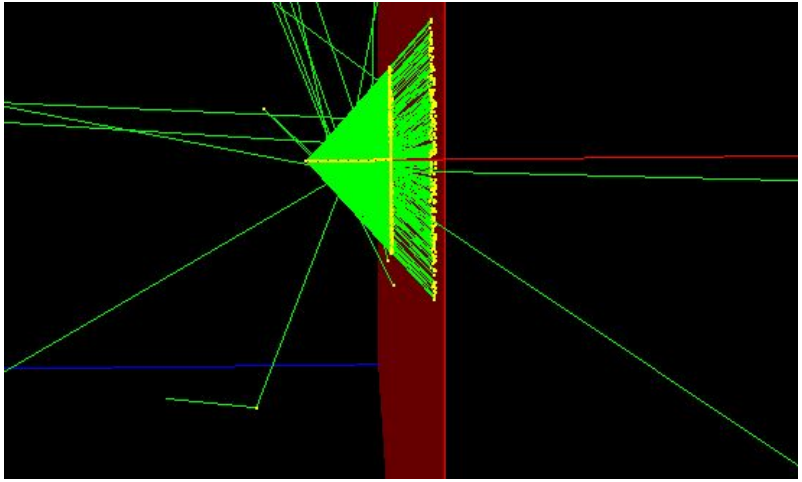
```
<matrix name="RINDEXLAR" coldim="2"
    values="7.74901*eV 1.31339 7.75673*eV 1.31368 7.76445*eV 1.31397 7.77217*eV
    7.94201*eV 1.32107 7.94973*eV 1.32139 7.95745*eV 1.32172 7.96517*eV 1.32204
    1.32958 8.14273*eV 1.32994 8.15045*eV 1.3303 8.15817*eV 1.33067 8.16589*eV
    8.33573*eV 1.33947 8.34345*eV 1.33987 8.35117*eV 1.34028 8.35889*eV 1.34069
    1.35014 8.53645*eV 1.3506 8.54417*eV 1.35105 8.55189*eV 1.35151 8.55961*eV
    8.72945*eV 1.36269 8.73717*eV 1.3632 8.74489*eV 1.36372 8.75261*eV 1.36424
    1.37641 8.93017*eV 1.377 8.93789*eV 1.37759 8.94561*eV 1.37819 8.95333*eV 1
    9.12317*eV 1.3928 9.13089*eV 1.39348 9.13861*eV 1.39416 9.14633*eV 1.39485
    1.41105 9.32389*eV 1.41184 9.33161*eV 1.41264 9.33933*eV 1.41344 9.34705*eV
    9.51689*eV 1.4333 9.52461*eV 1.43424 9.53233*eV 1.43518 9.54005*eV 1.43613
    1.45871 9.71761*eV 1.45983 9.72533*eV 1.46095 9.73305*eV 1.46208 9.74077*eV
    9.91061*eV 1.49061 9.91833*eV 1.49197 9.92605*eV 1.49335 9.93377*eV 1.49473
    1.52836 10.1113*eV 1.53005 10.119*eV 1.53176 10.1268*eV 1.53348 10.1345*eV
    10.3043*eV 1.57791 10.312*eV 1.58009 10.3198*eV 1.58228 10.3275*eV 1.5845 1
    10.505*eV 1.64282 10.5128*eV 1.64572 10.5205*eV 1.64866 10.5282*eV 1.65163
    10.7058*eV 1.73174 10.7135*eV 1.73583 10.7212*eV 1.73997 10.7289*eV 1.74418
    1.85553 10.9065*eV 1.86163 10.9142*eV 1.86785 10.9219*eV 1.87417 10.9296*eV
    2.06094 11.1072*eV 2.07141 11.1149*eV 2.08214 11.1226*eV 2.09314 11.1304*eV
    11.3002*eV 2.45554 11.3079*eV 2.47841 11.3156*eV 2.50217 11.3234*eV 2.52688
    11.5009*eV 3.65008 11.5086*eV 3.75265 11.5164*eV 3.86576 11.5241*eV 3.99131
```



Ĉerenkov Radiation

-When charged particles travel through a medium faster than the speed of light in that medium, they emit radiation. This radiation is emitted in the shape of a cone, described by the equation:

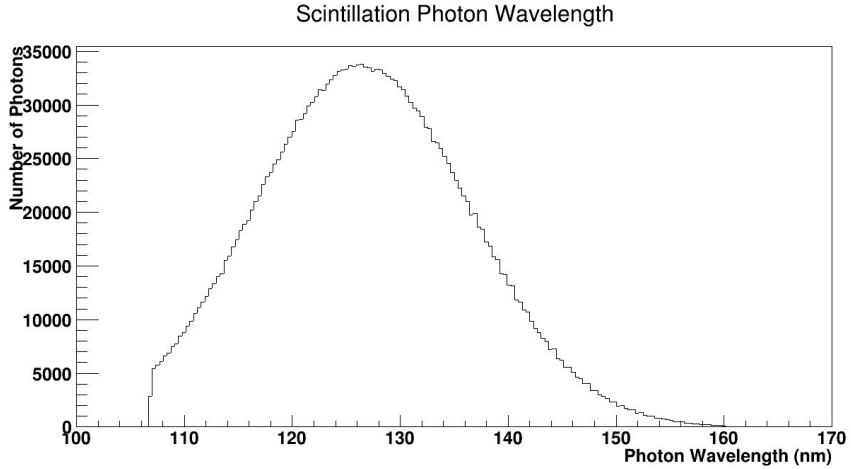
$$\cos\theta = \frac{1}{n\beta}$$



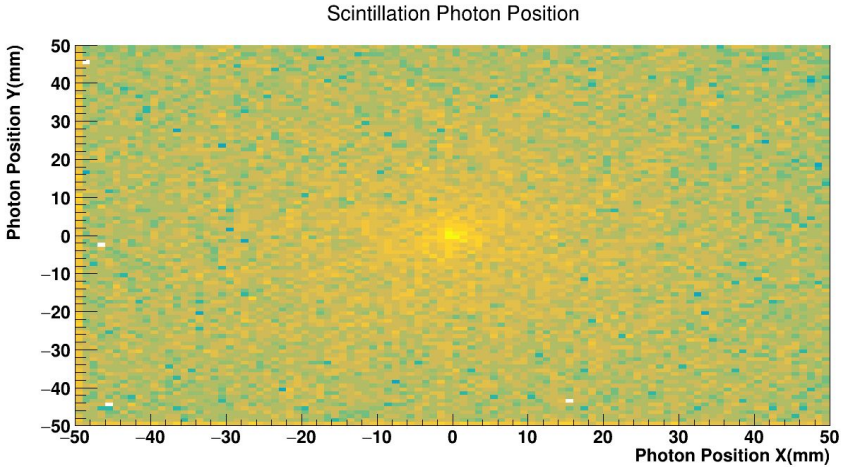
Scintillation

-Scintillation light is emitted by certain materials when transversed by charged ionizing particles.

-In Geant4, we see expected wavelength spectrums of photons emitted by scintillation:



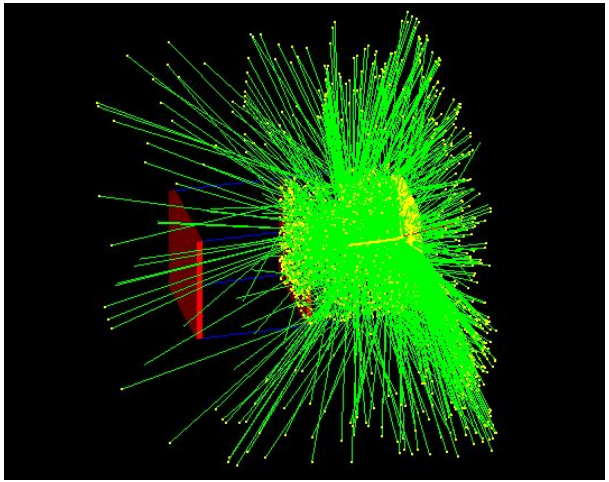
-Since scintillation is an isotropic process, we expect it to be released from all different directions equally.



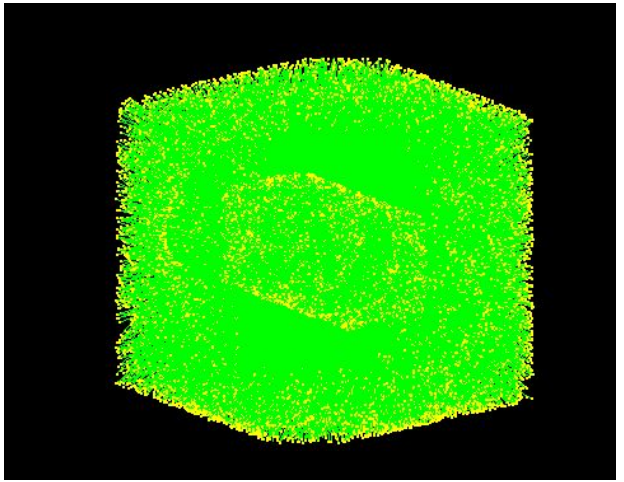
Scintillation Challenges

-Liquid Argon has scintillation yields of 50,000 photons emitted per 1 MeV of energy deposited in the material. An ionizing particle deposits 2 MeV per cm in LAr

-With high scintillation yields, each single event can take minutes to simulate.



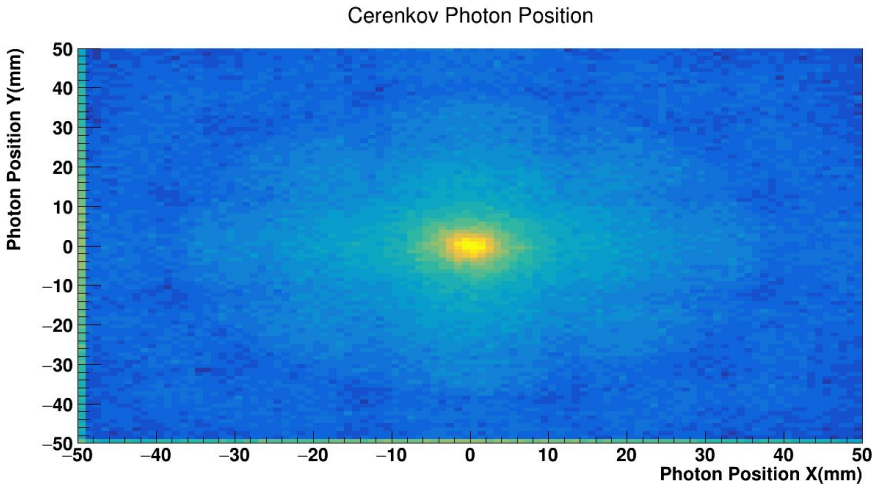
Scintillation Off

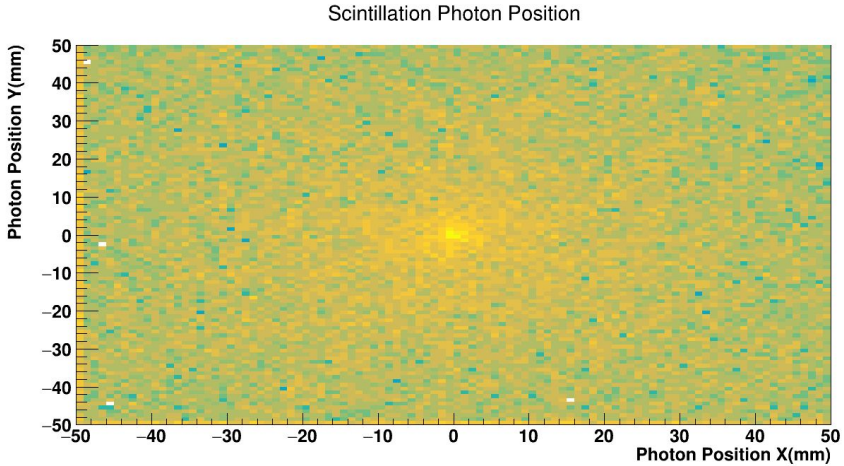


Scintillation On

Analysis

- Using G4AnalysisManager, you can make ROOT histograms and ntuples off of information registered at the various user actions:

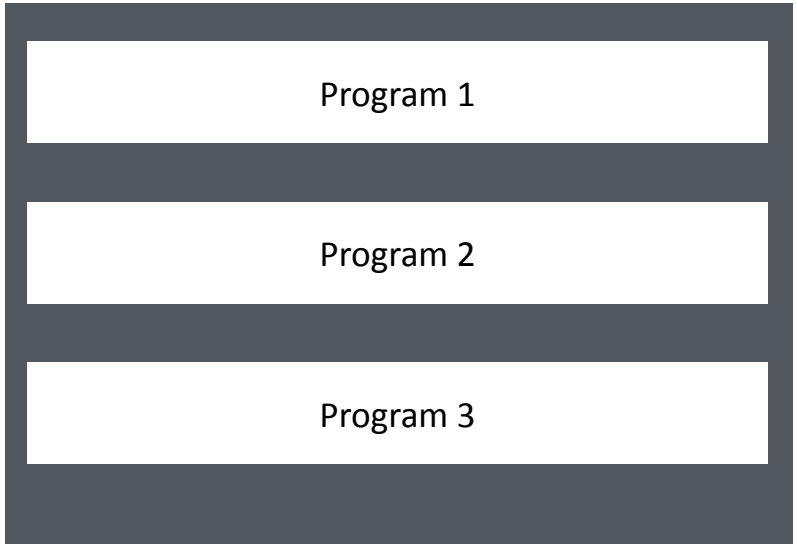




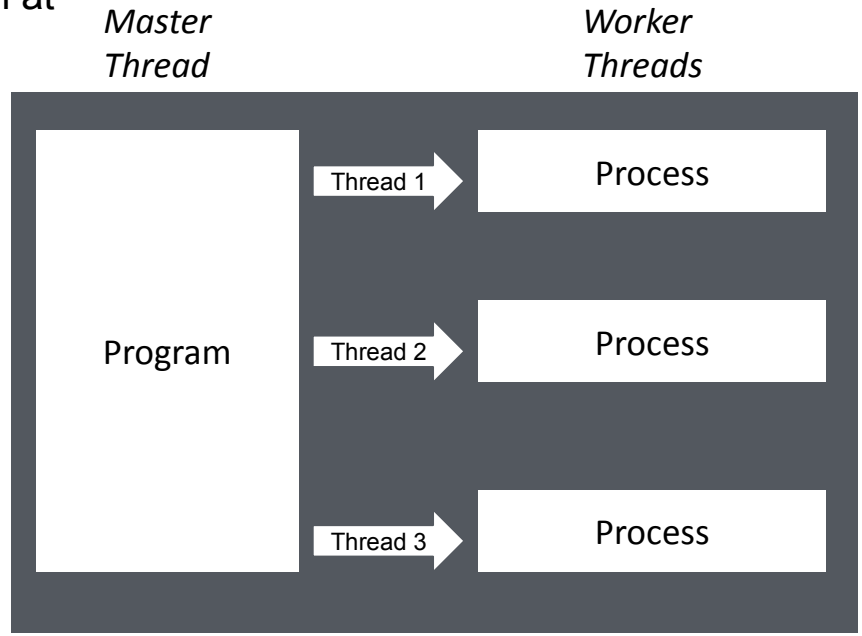
Performance Measurement

With single threaded programs, one can use multiple processes to utilize more of its computing cores

- Simply running multiple instances of the program at the same time, for example.



- With multithreaded programs, one can use multiple threads:

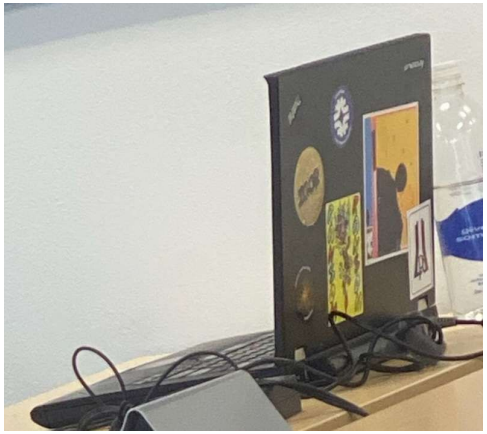


Performance Measurement Continued

- We will measure the number of events done per second.
  - Single threaded application
  - CaTS for multithreaded, with same GDML file

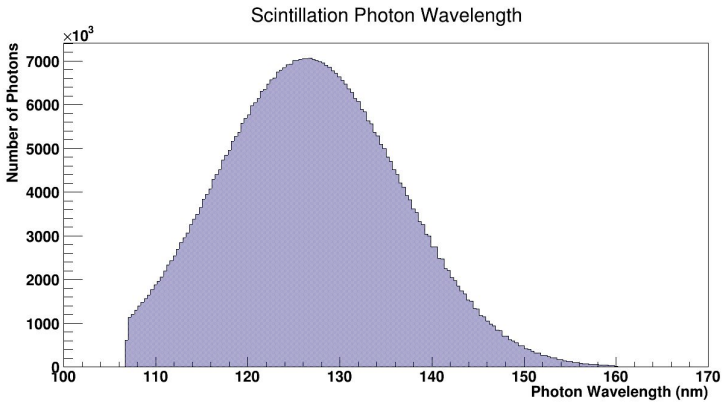
- We will also measure the amount of memory used by single threaded and multithreaded Geant4

- All this run in this machine:
  - 12Gb RAM
  - Intel(R) Core(TM) i5-2540M CPU @ 2.60GHz



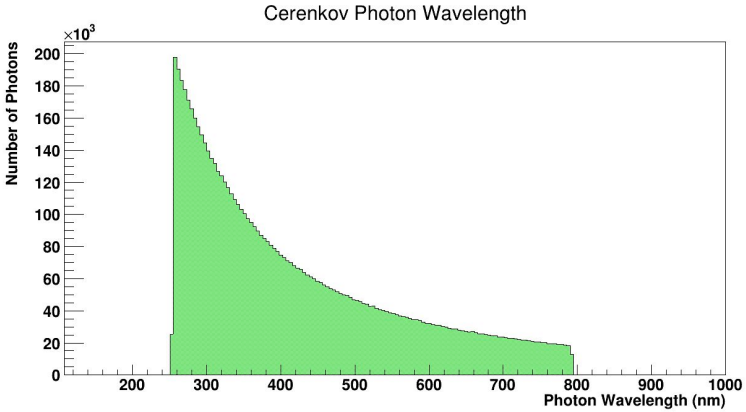
Experimental Validation

-To ensure the optical properties for the material are correct, data from the photons are recorded:



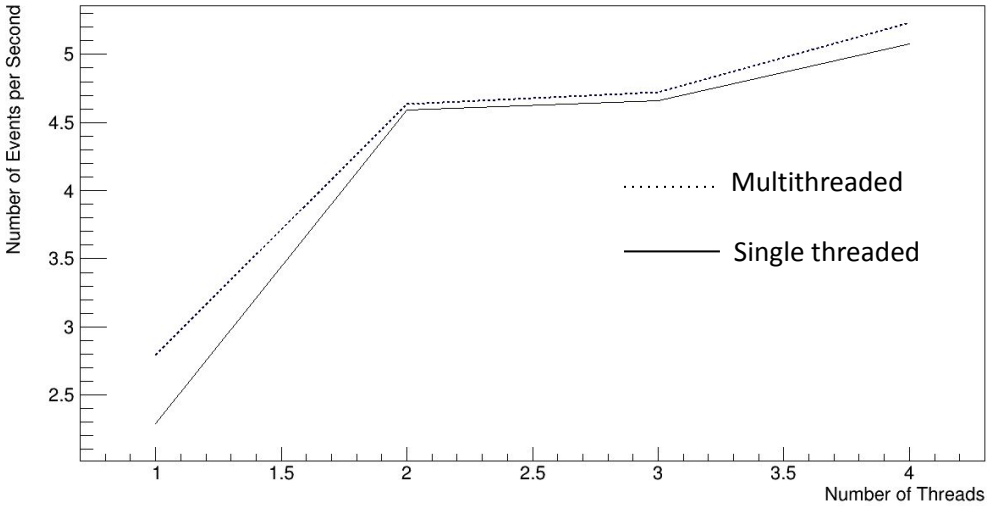
Wavelength of scintillation photons in LAr. *Photons are generated in the spectrum expected by LAr optical properties.*

-Same with Ĉerenkov:



Wavelength of Ĉerenkov photons in PbF2. *Photons are generated in the spectrum defined by the refractive indices of PbF2.*

Performance Results



- CPU Usage scales in the same way.

- In addition, we observe the memory increase in the multithreaded case is much lower than running multiple single threaded processes.
  - *Allowing you to use all CPU Cores when memory is sparse.*

Conclusion

- What did I learn?
  - Learned how to build and run Geant4 applications, a program used by particle physics and many other domains.
  - Learned about the Optical Processes in Geant4.
  - Learned how to analyze data generated by Geant4.
  - Would be able to apply this knowledge in a future projects requiring simulations.