Simulating detectors with Geant4 final presentation

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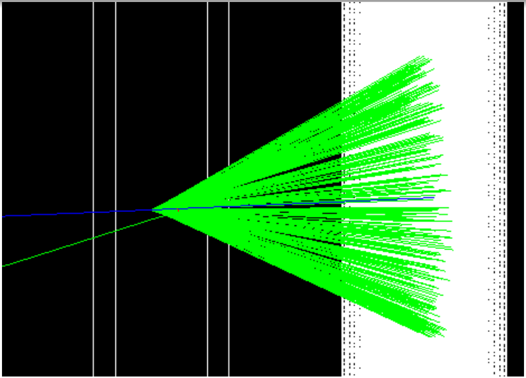
Geant4

- Particle and Nuclear physics simulations.
- Virtual detectors.
- Visualization of events.
- Support for: QT5, Python, multi-threading...
- CMake project.

Progress in the first half of the semester

- Setting up the environment. (VirtualBox + Ubuntu 18.04)
- Installing the software. (Geant4-10.7.03)
- Testing it by running an example. (B1)
- Learning the stepping stones of a simulation: (via Tutorial)
  - Run manager. (main function)
  - Detector construction. (geometry, material properties)
  - Action runner. (computation)
  - Particle generator. (particle properties)
  - Physics list. (laws of physics)
- Fixing issues. (optical photons, environment)
- Showcasing some output and saving data.

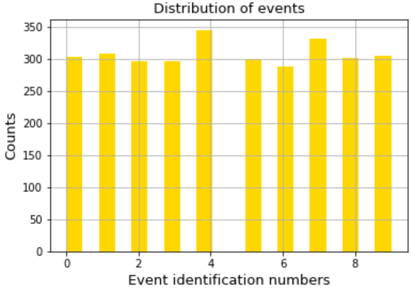
Cherenkov radiation (a proton and optical photons)

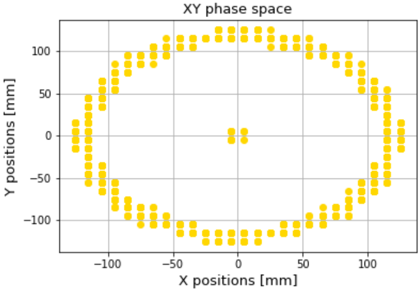


- Propagating the photons through the detector.
- Creating sensitive detectors.
- Electromagnetic interaction enabled in physics list.
- A proton passes through the detector and emits photons.
- Beta-electrons can also appear.
- Preparing output for analysis.

Preparing the yielded data for analysis

- Possibilities for saving data: ROOT, XML, CSV, HBOOK
- Installed ROOT and checked the output. (g4root)
- Opted for CSV for easier evaluation. (g4csv)





- Counts = Number of photons in an event.
- Uniformly distributed: mean of 308 ± 17 photons.

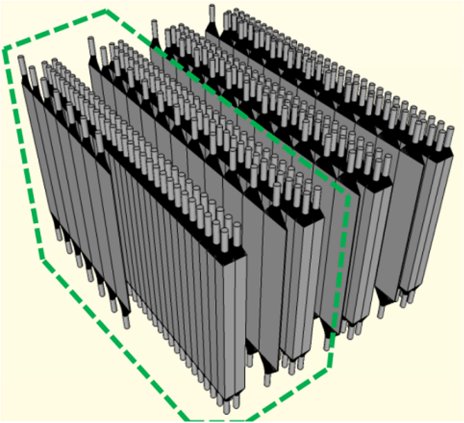
- Footprint of the photon cone.
- Low probability events in the middle.

Progress in the second half of the semester

- Studying the structure of the NEBULA detector.
- Trying to install smsimulator and failing at that.
- Using the simulation made by Balázs Pál.
- Making smaller modifications to the program and some fixing.
- Projecting a neutron beam through the detector.
- Exploring different physics lists.
- Grouping the relative number of particles via:
  - particle type,
  - generating process type,
  - detection volume type.
- Grouping the deposited energy by the same categories.
- Doing some analysis with the neutron generated protons.

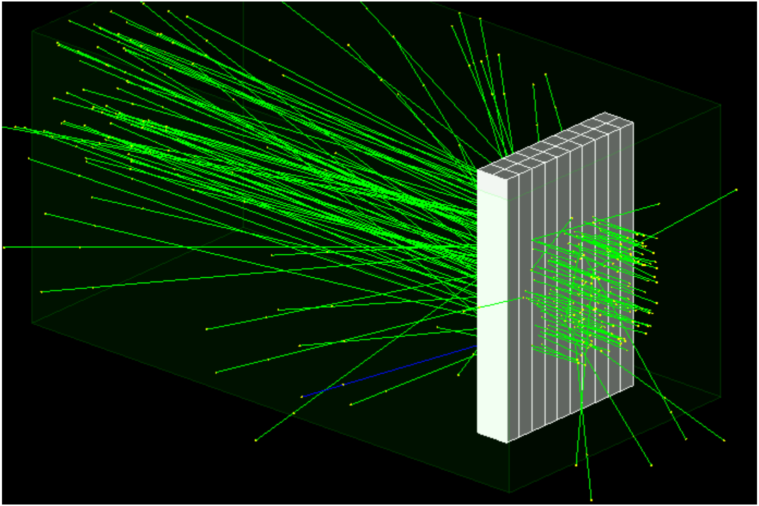
NEBULA detector

- Neutron (NEUT) and charged particle (VETO) detector modules.
- Enough modules for only two walls.
- Simulating only 20 NEUT modules here.



Neutron beam

- 100 uniformly distributed neutrons, each has 100 MeV energy.
- Many particles are difficult to visualize properly.



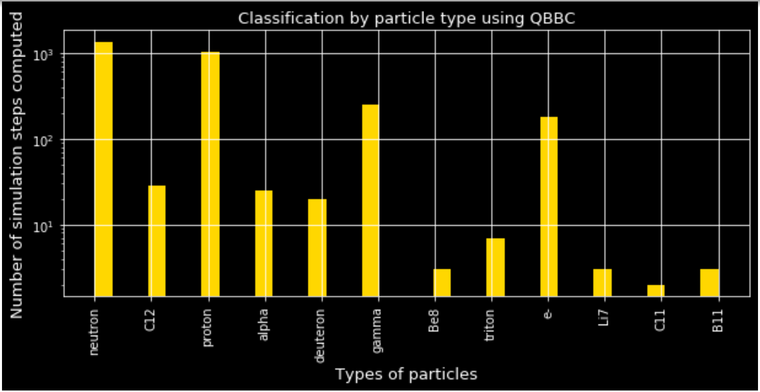
Physics lists

- QBBC: Geant4 Bertini and Binary cascade models
- QGSP: Quark Gluon String model for high energy hadronic interactions of protons, neutrons, pions, and Kaons
  - QGSP_BERT_HP: Geant4 Bertini cascade, data driven high precision neutron package (HP)
  - QGSP_BIC_HP: Geant4 Binary cascade, binary light ion cascade
  - QGSP_INCLXX: Liege Intranuclear Cascade model
  - QGSP_INCLXX_HP: Improved version of the previous one

Difference in output

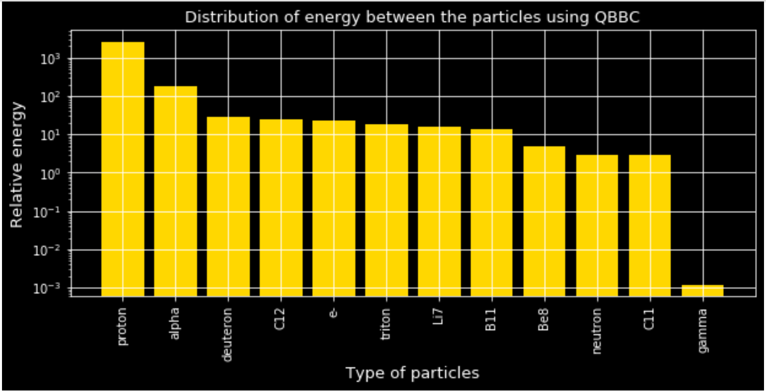
In the end, the main difference lies with the different types of low energy by-product particles that the physics lists allow to surface.

Results of classification (relative number of particles)



- Neutrons and protons dominate.
- Hadronic processes dominate.
- Fewer particles were detected on the sides of the wall.
- Many by-products are present with lesser significance.

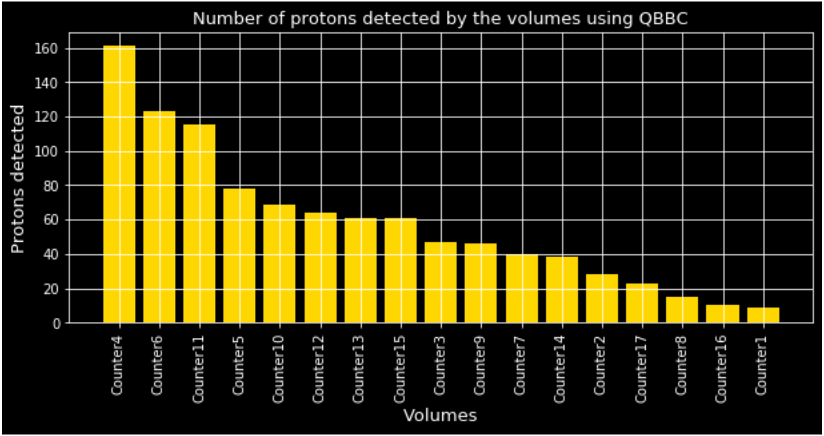
Results of classification (deposited energy)



- Protons deposited the largest amount of energy.
- Hadronic processes generated the most energy.
- Almost all of the energy was deposited into the NEUT modules. (Barely any into the enveloping volumes.)

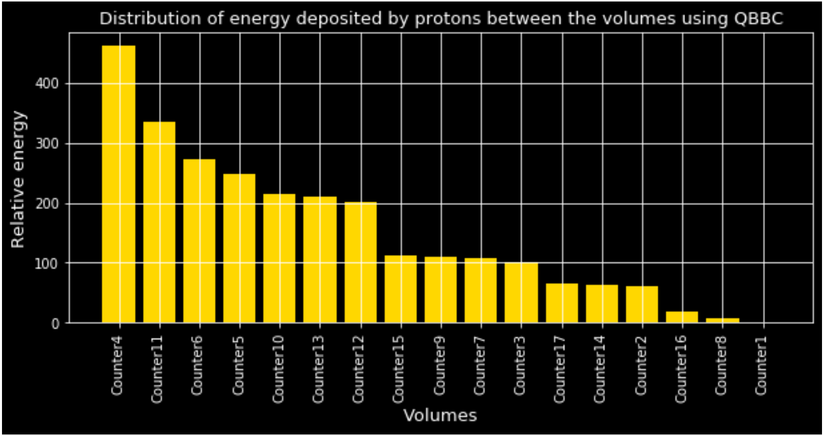
Analysis with protons pt. 1

- Protons are the most prominent by-products in this process.



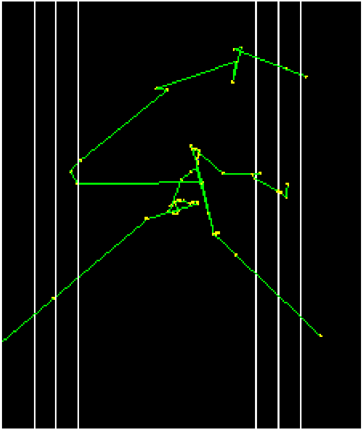
Analysis with protons pt. 2

- It would be nice to measure the distribution of deposited energy by a proton in each NEUT modules.
- Taking into account detector efficiency.



Analysis with protons pt. 3

- Problem: Each detection of the same particle counts as a separate particle of the same type.



Analysis with protons pt. 4

- Need to include TrackID to track individual particles.
- Can also include EventID to track whole events.
- TrackID by Volume matrix. (Total deposited energy.)

Volume	Counter10	Counter11	Counter12	Counter13	Counter14	Counter15
TrackID						
2	123.966944	199.363959	161.552077	142.447206	88.385260	274.892256
3	23.827213	74.126504	71.616980	27.241389	0.000000	73.322691
4	45.597451	0.342564	87.313399	2.005429	0.000000	11.459432
5	6.974643	0.109126	0.567521	3.690356	20.720280	6.462565
6	0.245689	0.199100	60.971124	0.082886	0.000000	0.740178
7	0.455911	0.000000	10.711390	0.897820	0.000000	0.321943
8	0.563960	0.000000	0.000000	2.891754	0.000000	0.251923
9	0.090272	38.458020	0.000000	24.210400	0.000000	20.236061
10	0.114695	0.000000	0.000000	5.340050	0.000000	4.698714
11	0.000000	0.000000	0.000000	5.048784	0.000000	3.429324
12	0.000000	0.000000	0.000000	2.372940	0.000000	0.409654

Analysis with protons pt. 5

Results can be viewed here:

- https://github.com/borbende/Scientific-Modelling-Computer-lab/blob/main/the_end/figures/mat1.png
- https://github.com/borbende/Scientific-Modelling-Computer-lab/blob/main/the_end/figures/mat2.png
- https://github.com/borbende/Scientific-Modelling-Computer-lab/blob/main/the_end/figures/mat3.png
- https://github.com/borbende/Scientific-Modelling-Computer-lab/blob/main/the_end/figures/mat4.png
- https://github.com/borbende/Scientific-Modelling-Computer-lab/blob/main/the_end/figures/mat5.png

Differences between runs

Number of protons, energy deposited, accountable volumes.

Sources and tools

- Oracle VM VirtualBox: https://www.virtualbox.org/wiki/Downloads
- Ubuntu 18.04: https://ubuntu.com/download/desktop
- Geant4: https://geant4.web.cern.ch/support/download
- ROOT: https://root.cern/install/
- Python: https://www.anaconda.com/
- Tutorials: https://www.youtube.com/channel/UCyxwnZPodqQR0hUo5sapRFw
- NEBULA detector official site: http://be.nucl.ap.titech.ac.jp/~nebula/index.php
- Smsimulator official site: http://be.nucl.ap.titech.ac.jp/~nebula/simulator.php
- RI Beam factory informations: https://www.riken.jp/en/collab/resources/ribf/
- Balázs Pál simulation: https://github.com/masterdesky/ELTE_Modelling_Lab_2021/tree/main/project/project_nebula/NEBULA

End notes

- Geant4 is very hard to master.
- Even with tutorials, coding and debugging can be a nightmare.
- Significant progress was made in the project during the semester.
- Not all aims were accomplished: automatization.
- Numerous issues arose: environmental, compatibility, coding issues which delayed progress sometimes by weeks.
- All in all, I have acquired basic knowledge about working with Geant4 and analysing data yielded by its simulations.
- My github: `https://github.com/borbende/Scientific-Modelling-Computer-lab`
- Consultants provided invaluable help. Thank you, Ákos Horváth and Balázs Pál!

Thank you for your attention!