Development of a Physics List for Radiation Protection Studies in Space

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within the Geant4-DNA Collaboration

Brief Background

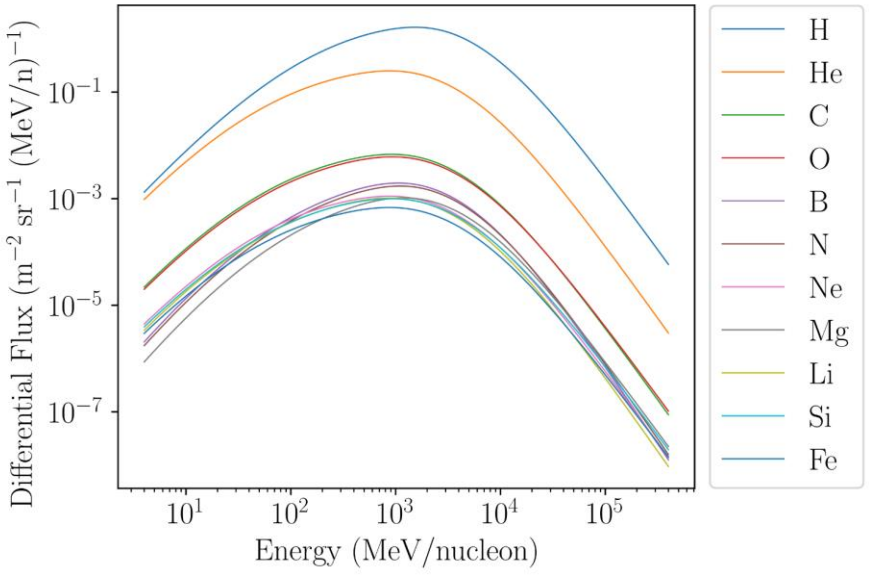
- Beyond the surface of Earth, the lack of atmosphere and magnetosphere results in a harsher radiation environment

- Understanding the radiation environment in vital organs and potential DNA damage paramount to astronaut safety
- Current focus on lunar mission

[1] – Dobynde et. al., 2021. *Space Weather*, **19**

Lunar Radiation Environment

- The radiation environment on the moon consists of primary GCR particles and secondary radiation generated within the lunar volume

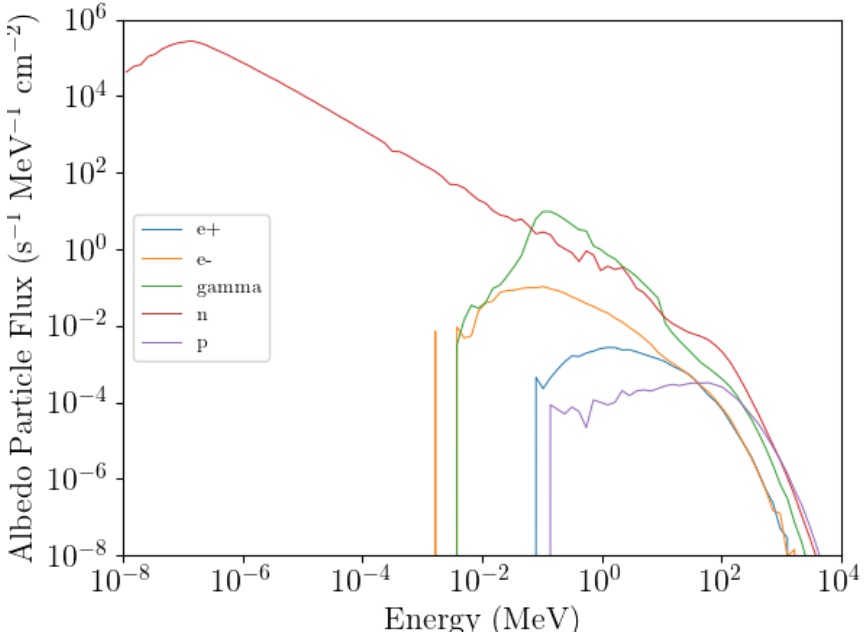


GCR spectrum during solar minimum as modelled using SPENVIS [1]

- Primary GCR particles mainly high energy protons
- Other ions must also be considered due to larger dose equivalent (He, C, Fe at least)

Lunar Radiation Environment

- The secondary radiation leaving the lunar surface is simulated using a multi-layer lunar volume

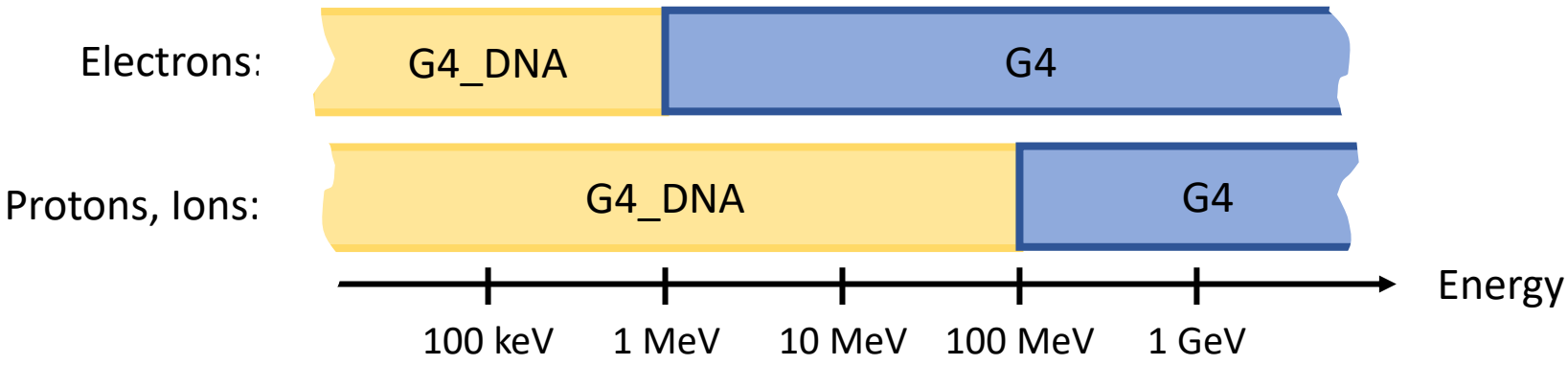


Secondary particles generated from the lunar surface from GCR protons [1]

- Secondary radiation consists of many low energy neutrons
- Heavier fragments also occur with lower frequency

Geant4-DNA Space Physics List

- Current Geant4-DNA models for particles of interest include:
  - e^-: up to 1 MeV
  - Protons: up to 100 MeV
  - Ions: up to 100 MeV
  - Simulated Ions: ^{7}Li, ^{9}Be, ^{11}B, ^{12}C, ^{14}N, ^{16}O, ^{28}Si, ^{56}Fe
- Thus, much of the GCR and secondary radiation spectrum can not be simulated using Geant4-DNA models
- Current approach: development of a hybrid physics list
  - Geant4-DNA physics models in applicable energy range
  - Geant4 physics models applied outside of these ranges



Geant4-DNA Space Physics List

- As of Geant4.11.01-beta01, the implementation of the *G4EmDNABuilder* class includes a method for initialising Geant4 physics outside of the applicable Geant4-DNA range
- However, activation of this technique leads to conflicting results of radiochemical yields:

Radiochemical Yields

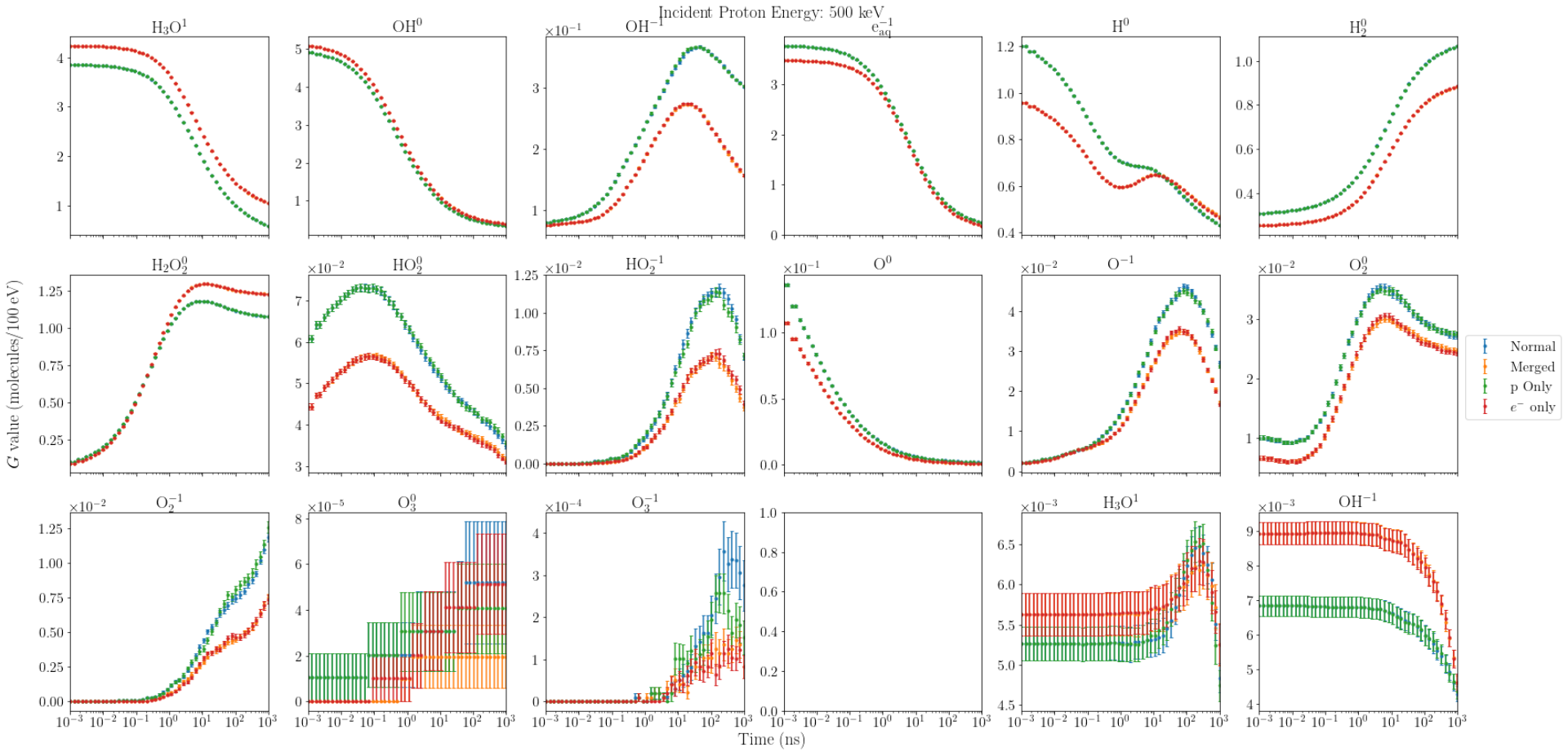
- The chem6 extended example scores the radiochemical yield *G* which is a function of time and LET:

$$G = \frac{\text{Number of species}}{100\text{eV of deposited energy}}$$

- The geometry is a water box
- Scoring of radiochemical species is performed between 1ps and 1us.

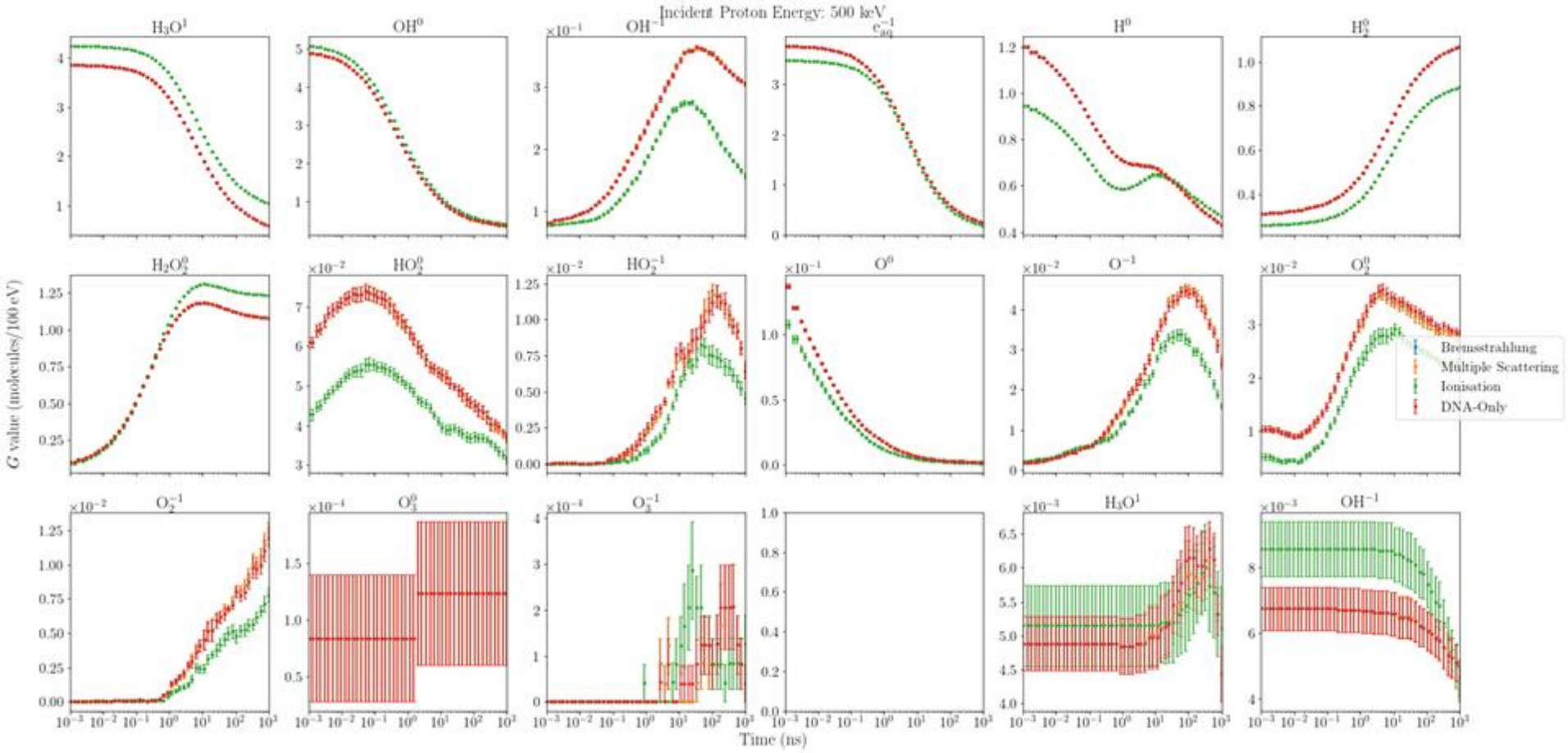
Radiochemical Yields

- Radiochemical yields tracked for different proton energies and different physics list combinations
- Variations when Geant4 physics is enabled for electrons in the *Geant4-DNA energy range for electrons*



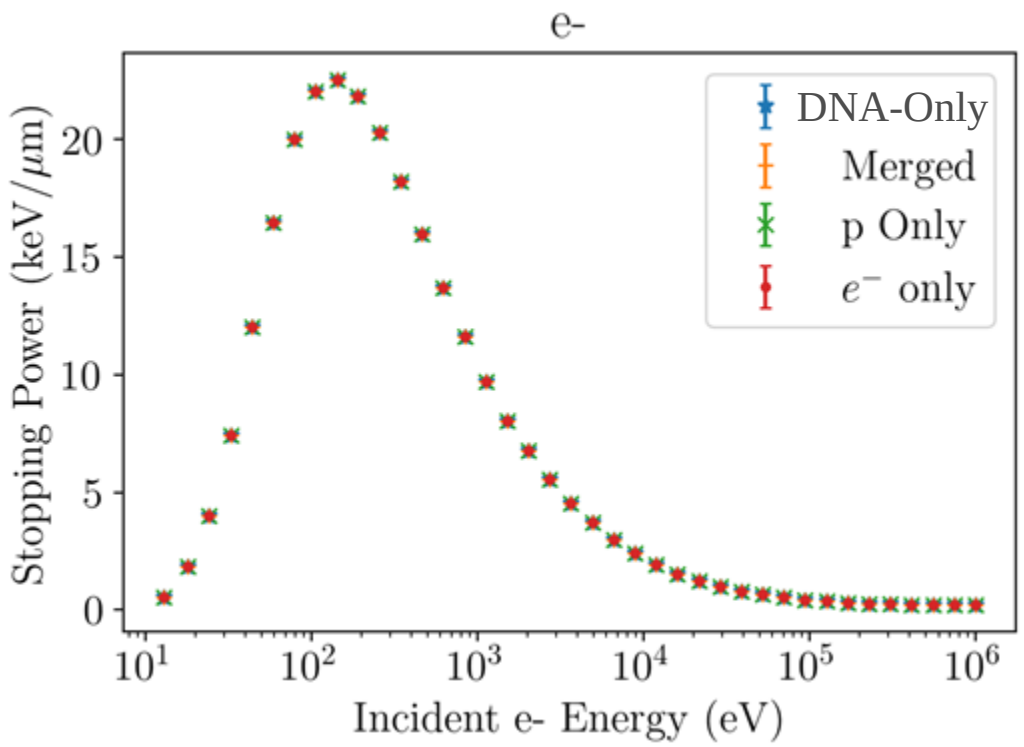
Radiochemical Yields

- *G* tracked for activation of different electron physics processes
- Difference arises only upon activation of Geant4-DNA e^- *ionisation* models



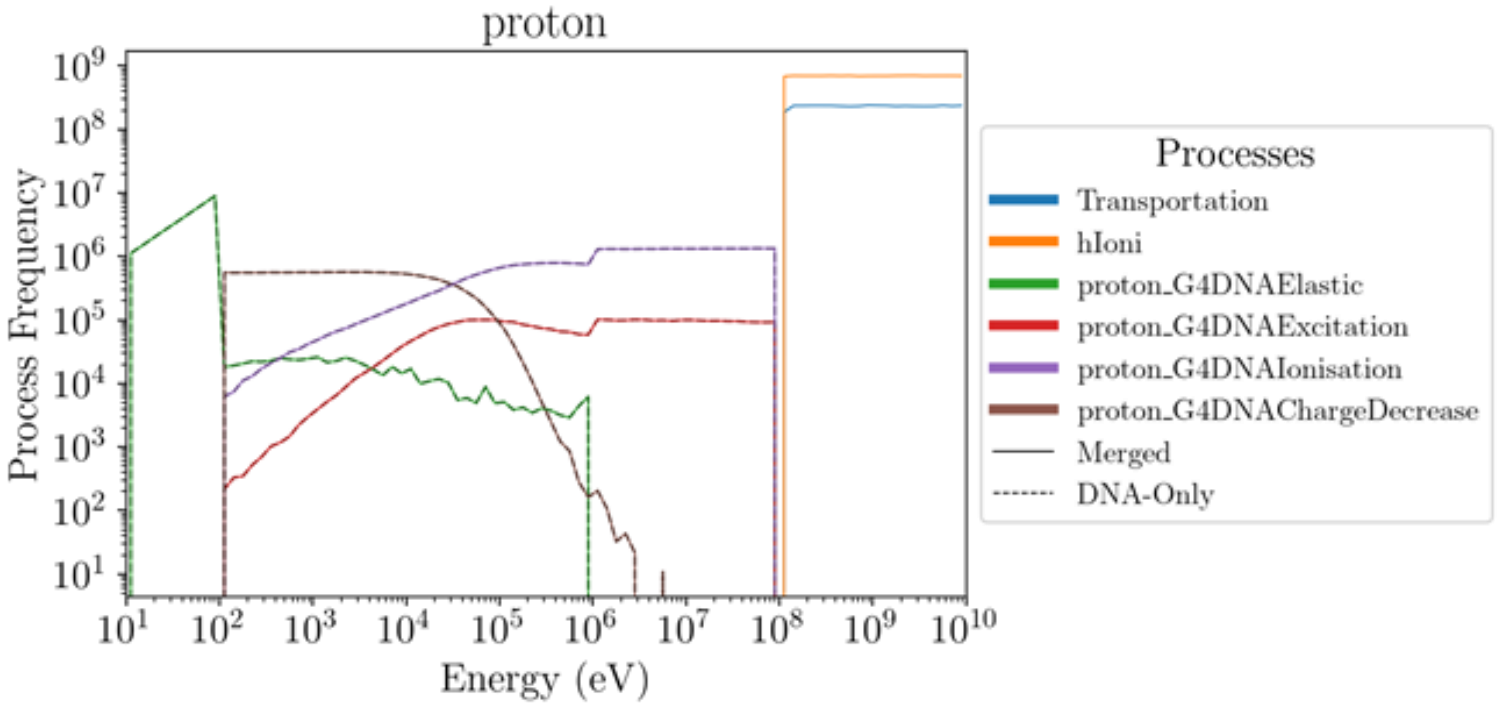
Physics Processes Validation

- The stopping power of electrons and protons are the same for all energies, regardless of Geant4 and Geant4-DNA combination



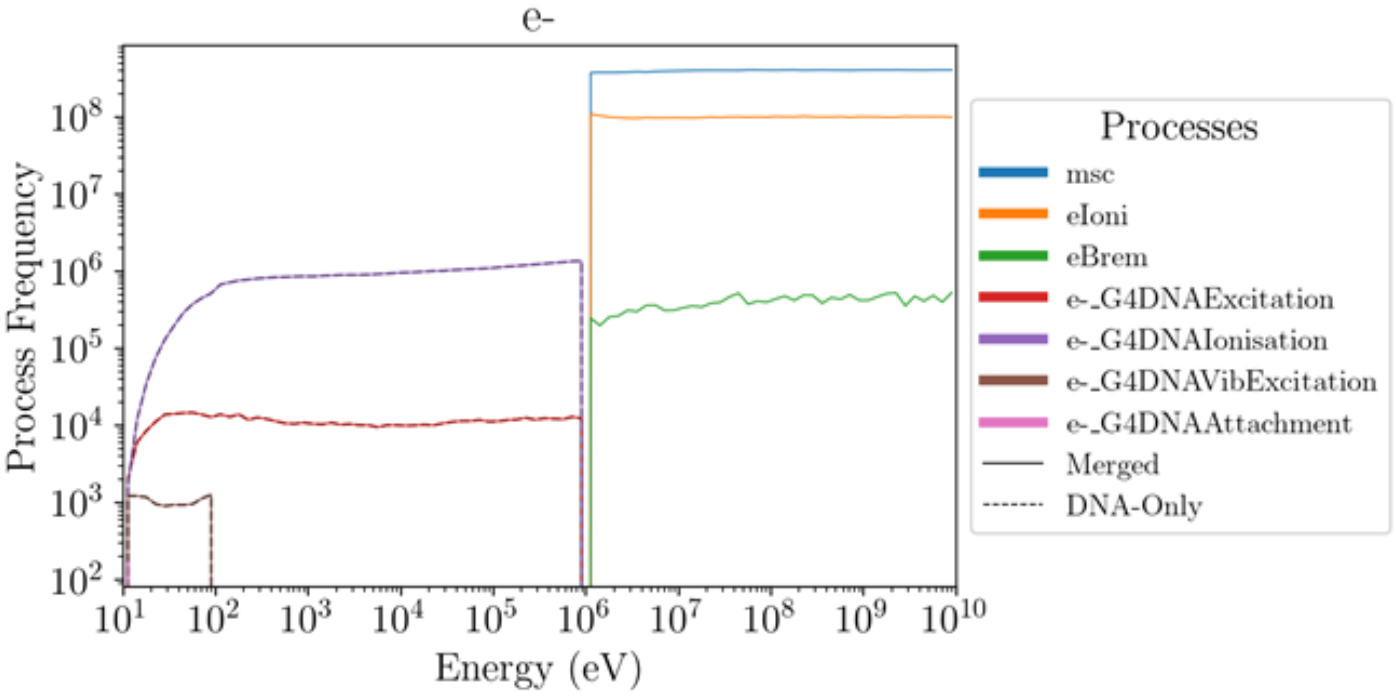
Physics Processes Validation

- The occurrence of physics processes was tracked for e^-s and protons in water as a function of energy
- Scoring only the first process for an incident particle shown below
- No variation in the process frequency is observed for protons



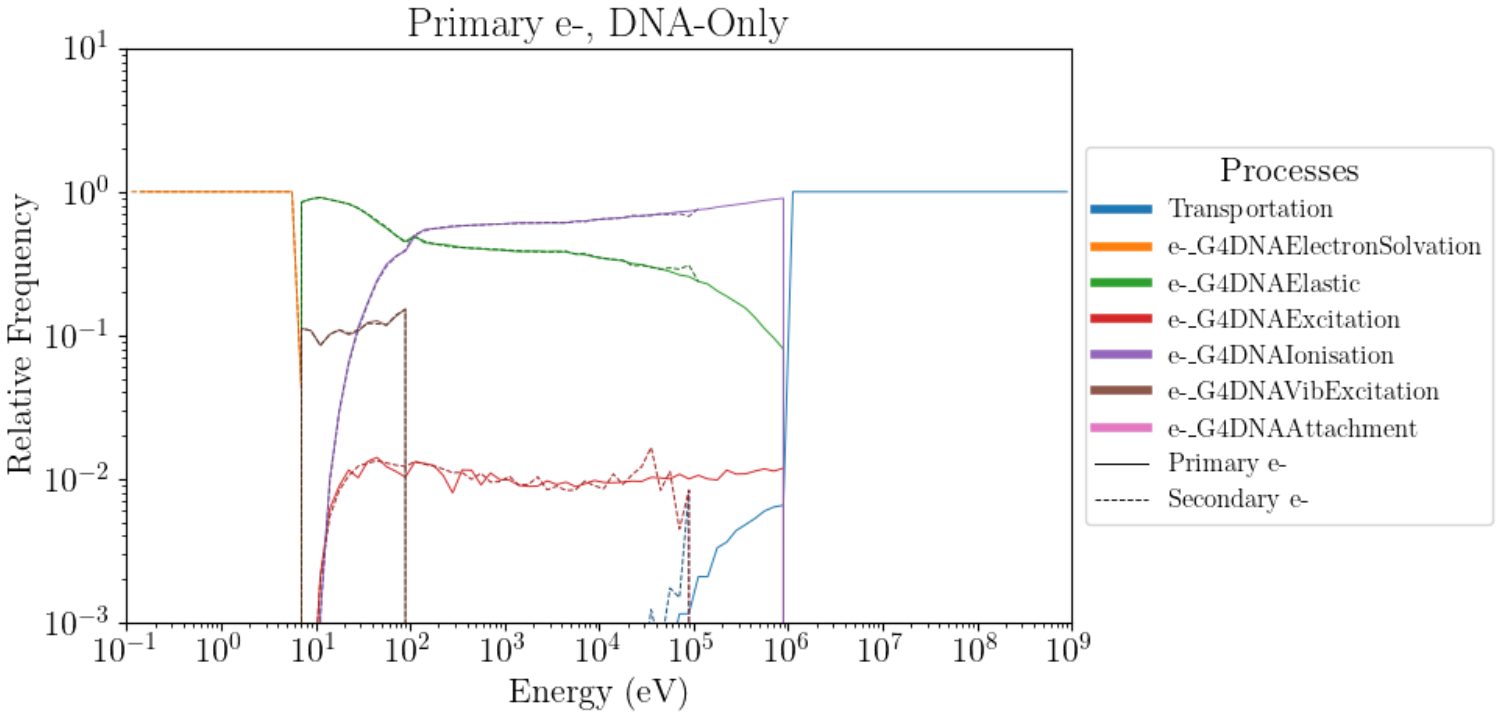
Physics Processes Validation

- The occurrence of physics processes was tracked for e^-s and protons in water as a function of energy
- Similarly, no difference observed for the first process in electrons:



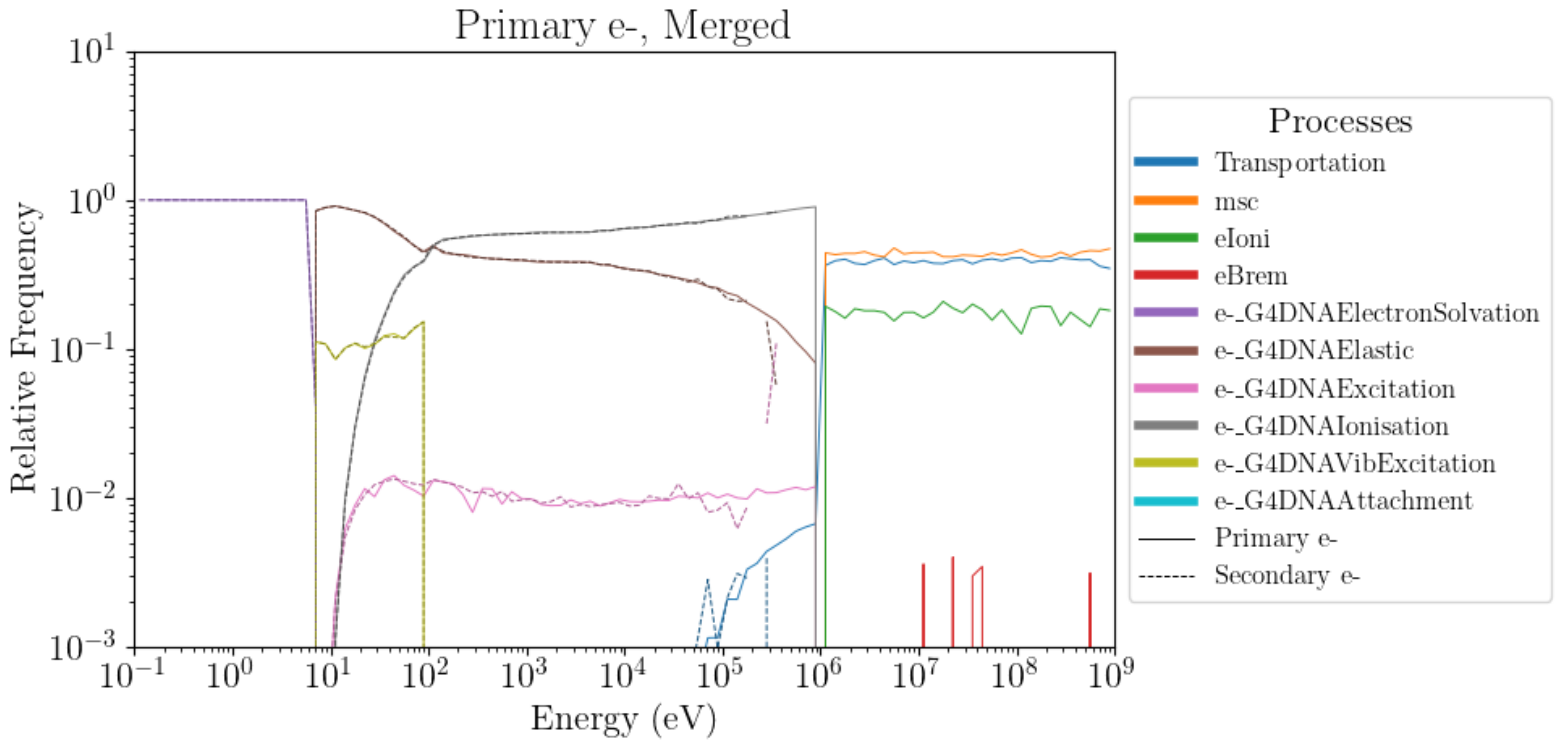
Physics Processes Validation

- To check whether additional processes occur for secondaries, the relative frequency of processes for primary and secondary electrons were tracked
- No differences in the process frequency observed between primaries and secondary electrons for Geant4-DNA only physics



Physics Processes Validation

- To check whether additional processes occur for secondaries, the relative frequency of processes was tracked for different energies
- No differences in the process frequency observed between primaries and secondary electrons for the merged physics list



Conclusions

- Goal: develop a hybrid Geant4 and Geant4-DNA physics list for cosmic nanodosimetry
  - To be coupled then with hadronic physics
- Currently, a hybrid em physics list causes an increased radiochemical yield due to e^- ionisation activation
- However, the frequency of the process is not observed to change so the origin is still unknown
- Any comment/suggestion would be helpful