The effect of single Coulomb scattering on Cherenkov emission

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Introduction

- Charge particle that moves faster than $\frac{c}{n}$ in medium emits Cherenkov radiation [1].
- Current simulation tools, as Geant4 [2], assume that the charged particle moves with a constant velocity and at a straight line.
- Modern particle physics experiments like SNO+ rely on these simulations.
- But how well do we model Cherenkov light?

Approach

- In reality, a particle experiences innumerable collisions while traveling in the water.
- Cherenkov light is produced by interference of the EM waves. Therefore, the shape of the trajectory may influence the resulting interference pattern.

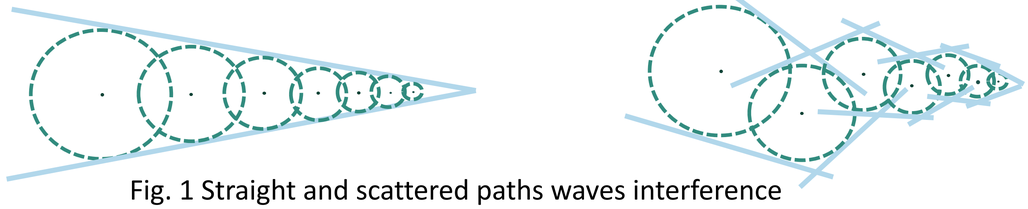

Fig. 1 Straight and scattered paths waves interference

- Next formulas help us to consider interference effects between path segments [3]:

$$P_{k\omega}(\boldsymbol{r}) = \frac{nk^2}{2\pi r^2 c}\left|\sum_{\nu=1}^{N} I_\nu\right|^2, I_\nu = \frac{e}{2\pi}\sin\Theta_\nu\, e^{i(\delta_\nu+\chi_\nu)} l_\nu \frac{\sin\chi_\nu}{i\chi_\nu}$$

- To get more physically precise trajectories, we use a single Coulomb scattering model.

Why single scattering?

- To preserve coherence, straight path length L should be > 4λ/n. We are interested in λ/n ≈ 300nm, hence L > 1.2 μm for water [4]. Whereas the electron's free mean path is ≈1 μm.
- Commonly used multiple scattering model in geant4 is an approximation. Step is ≈100μm.
- Coulomb single scattering model describes each interaction with a step of ≈1μm.

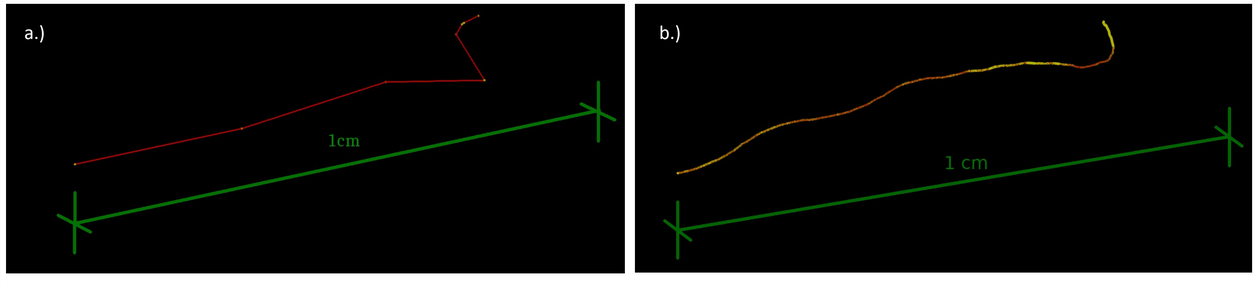

Fig. 4 a.) Multiple scattering and b.) Single scattering 2 MeV electron trajectory

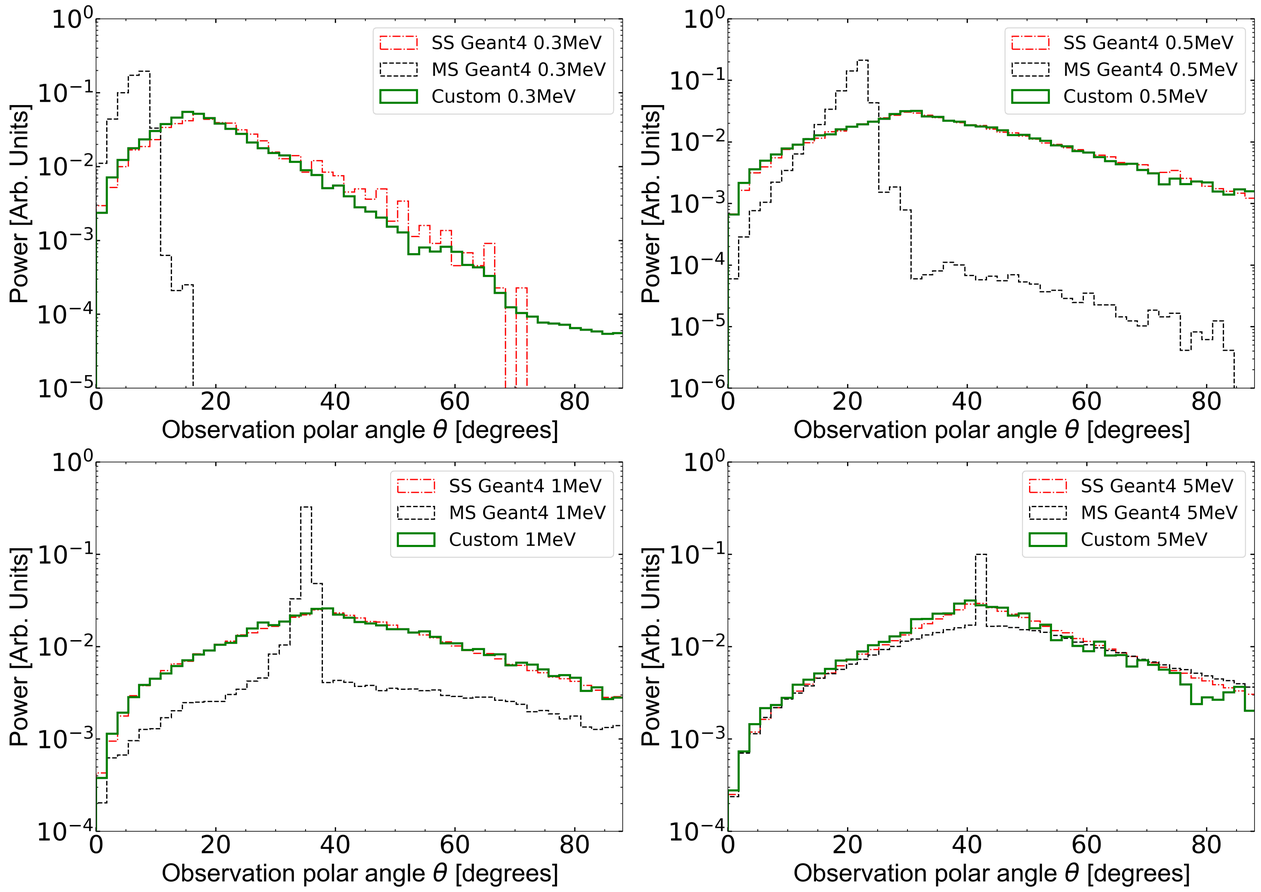

Fig. 3 Angular dependence of the Cherenkov light as they would be observed in a spherical detector, created by the electrons injected along the z-axis. SS – single scattering, MS – multiple scattering.

Results

- There are significant differences between multiple (MS) and single scattering (SS) models.
- The more physically accurate calculations have demonstrated minimal deviations from the current simulation tools for the SS model (MS is used by default).
- The light output (number of emitted photons) will be calculated next.
- The results will be compared to the SNO+ experiment data.

References

1. I.M. Frank and I.E. Tamm, Dokl. Akad. Nauk SSSR 14, 109 (1937).
2. S. Agostinelli et al., Nuclear Instruments and Methods in Physics Research Section A, 506 (2003)
3. K.G. Dedrick, Phys. Rev. 87 (1952) 891.
4. R.J Komar, SNO-STR-95-67 (1995)