Detailed comparison of the SENECA and CORSIKA shower simulation packages

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***Abstract*. The SENECA extensive air shower simulation program uses a hybrid simulation method, combining cascade equations and full Monte Carlo simulation. By using cascade equations in the high energy regime, where the shower is one dimensional, and full Monte Carlo at energies below which the shower begins to become three dimensional, SENECA produces air shower simulations quickly and accurately. In this study, we compare SENECA and CORSIKA in a detailed manner, for simulated showers with identical first interactions, so that they can be compared on an event-by-event basis. We compare the final longitudinal profile, lateral distribution function, energy distribution of ground particles, and the propagation of particles in the atmosphere predicted by SENECA and CORSIKA. We find that CORSIKA and SENECA are in agreement within the current statistical uncertainties arising from the size and thinning level of our library, which will be improved for the presentation at ICRC.**

***Keywords*: SENECA, simulations, airshowers**

I. INTRODUCTION

SENECA is a Monte Carlo (MC) air shower simulation program which combines cascades equations and full MC to quickly and acurately produce simulated air showers, providing both longitudinal profiles (LP) and lateral distributions of ground particles [1]. The hybrid approach implemented in SENECA consists of simulating the first interactions in full MC, utilizing cascade equations to when the shower is sufficiently high energy to be one-dimensional, and then completing the simulation with a full MC for the low energy particles. In this study, we compare air showers simulated with SENECA to air showers simulated with CORSIKA, a well tested full MC air shower simulation program [2]. We look for discrepancies in the LP, the lateral distributions function (LDF), energy distribution of ground particles, and propagation of particles in the atmosphere.

II. COMPARISONS ON AN EVENT-BY-EVENT BASIS

Natural shower-to-shower fluctuations give rise to a large variance in the LP and LDF. We simulate the same first interactions in both SENECA and CORSIKA, which reduces fluctuations seen from one simulated air shower to another and allows for stronger comparisons to be made. Previously, we have used this method to expose an insufficient treatment of the photonuclear effect in older versions of SENECA [6]. The treatment of photonuclear interactions has been improved, and we use newer versions of SENECA to test the accuracy of SENECA against a standard in air shower simulation codes.

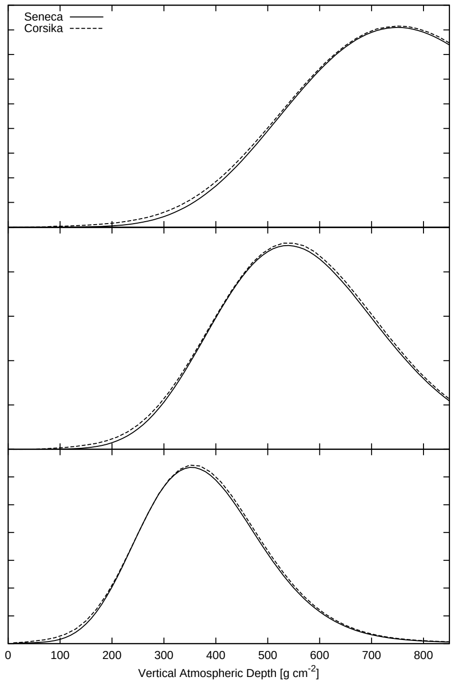

Fig. 1. A comparison of the longitudinal profiles produced from a fixed first interaction. The top figure is for a vertical shower, the middle figure is for a shower at $45°$, and the botton figure is for a shower at $60°$ inclination. The horizontal axis is the vertical column depth, and the vertical axis is the energy deposition.

III. LIBRARY OF EVENTS

Our library was generated using SENECA version 1.3.7, and CORSIKA version 6.735. We simulated proton initiated events, with an energy of 10 EeV, at zenith angles $0°$, $45°$, and $60°$. At each zenith angle, 100 showers were produced with the same first interaction in both SENECA and CORSIKA, using a thinning level of 10^{-5} with weight limitations. QGSJET01 was used for the high-energy hadronic model, and Fluka2008 was used as the low energy model [3], [4], [5]. 100 showers at this thinning level is isufficient to precicely determine any discrepancies, but is adequate to test for large discrepancies.

IV. COMPARISON OF LONGITUDINAL PROFILES

The longitudinal profiles produced by SENECA and CORSIKA have been previously shown to agree well on

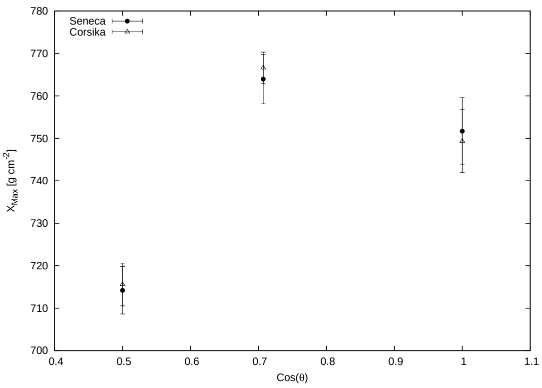

Fig. 2. The average X_{Max}, in gcm^{-2}, as a function of $cos(\theta)$ for three fixed first interactions.

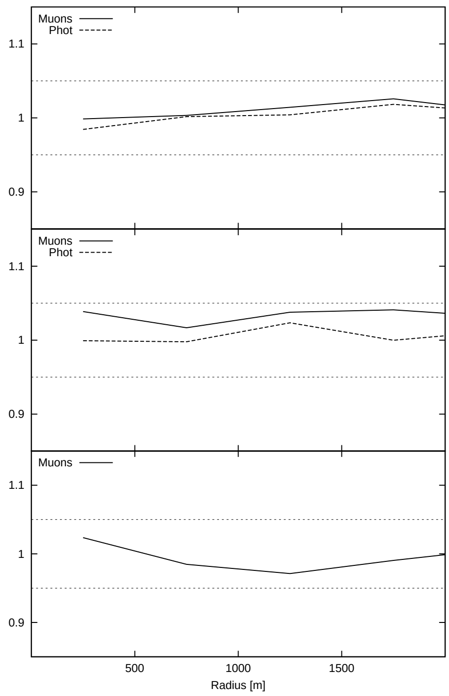

Fig. 3. The ratio of the averaged LDFs of 100 showers for three fixed first interactions, for simulations where photonuclear interactions have been removed, and SENECA is being run in full MC mode. The muon curve represents the ratio of the number density in SENECA to the number density in CORSIKA, while the photon curve represents the ratio of the energy density in photons in SENECA to that in CORSIKA. The top figure is for a vertical first interaction, and the middle and bottom figures are for a first interaction with an inclination of $45°$ and $60°$ respectively.

average [7]. We use our library to compare the energy deposition profile and X_{Max} for a single first interaction. Figure 1 shows the LP, averaged over the 100 realizations of the subsequent interactions, for each zenith angle. Apart from a difference in the early development of the shower, discrepancies are at the level of a few percent. We show the comparison between X_{Max} for the showers in Figure 2. Both the mean and the width of the distributions are consistent.

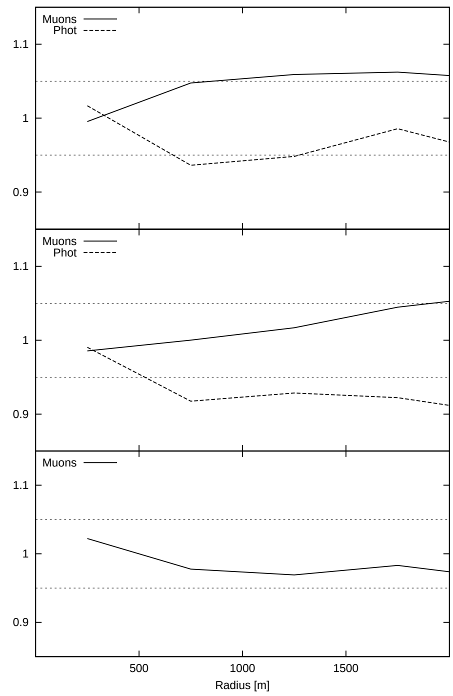

Fig. 4. The ratio of the averaged LDFs of 100 showers for three fixed first interactions, where SENECA is being run in the hybrid mode. The muon curve represents the ratio of the number density in SENECA to the number density in CORSIKA, while the photon curve represents the ratio of the energy density in photons in SENECA to that in CORSIKA. The top figure is for a vertical first interaction, and the middle and bottom figures are for a first interaction with an inclination of $45°$ and $60°$ respectively.

V. Comparison of Lateral Distribution Functions

Due to the difference in the treatment of photonuclear interactions, and their considerable impact upon the LDF of showers, we compared the LDFs of the SENECA and CORSIKA simulated showers with and without photonuclear interactions. Since photonuclear interactions are built into the cascade equations, comparisons of SENECA and CORSIKA without photonuclear interactions can only be fairly done when operating SENECA in a full MC mode. The ratio of the SENECA LDF to the CORSIKA LDF as a function of core radius, when photonuclear interactions are turned off, is shown in Figure 3. Seneca in the full MC mode agrees very well with CORSIKA, and differences are no more than a few percent. The same comparison with photonuclear interactions and utilizing the cascade equations is shown in 4. Photons were not compared at $60°$ due to insufficient statistics. A maximum difference of up to 10% is seen, with a typical difference closer to 5%. Given the current statistical uncertainty arising from our library, we conclude there are no strong discrepancies, and they are in general agreement at the current precision.

VI. Energy Distribution of Ground Particles

The normalized energy distributions of muons and photons at $1000km$ is shown in Figure 5. Similar to the LDF comparison, we find there is no strong discrepancy.

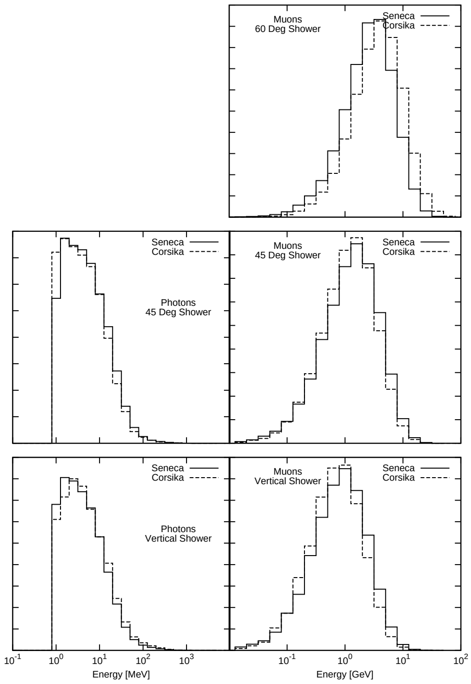

Fig. 5. A comparison of the energy distributions predicted by SENECA and CORSIKA for muons and photons for fixed first interactions at various angles.

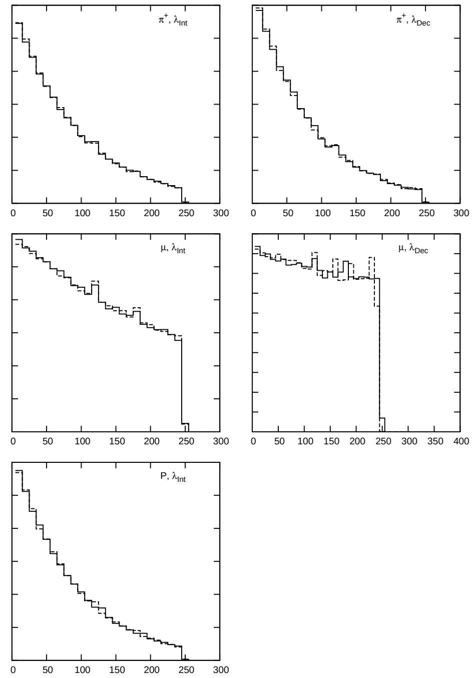

Fig. 6. A comparison of the interaction and decay lengths for π^+, μ, and protons, as calculated in SENECA and CORSIKA. The left column compares the interactions lengths, while the right column compares the decay lengths. Both the π^+ and proton plots are for particles with energies of $100GeV$. The μ decay comparison is for muons at $1GeV$, whereas the interaction comparison is for muons at $10TeV$.

VII. Propagation of Particles

To test the accuracy of SENECA in the full MC mode, modifications were made to both SENECA and CORSIKA that allowed for particles to be tracked through a single step in the atmosphere. In Figure 6, we show the interaction length and decay length of charged pions, muons, and protons. The charged pions and protons are compared for energies of $100GeV$, while the muons are compared at energies of $10TeV$ for the interaction length and $1GeV$ for the decay length. The results here are typical: SENECA and CORSIKA predict nearly identical propagations lengths in the atmosphere for all hadronic partciles and muons.

VIII. Conclusion

By utilizing the same first interaction in SENECA and CORSIKA, one can make very detailed comparisons. We have looked into the results of air shower codes that are of greatest interest to experiments and have found reasonable agreement. Given the statistics and thinning used in this study, we are unable to determine the exact level of agreement, but we find no reason to suspect large discrepancies. A continuation of this study with higher statistics and lower thinning will be presented at the conference.

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