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Muon Deflection Simulation Using PROPOSAL

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Introduction

In large scale neutrino telescopes and muography incoming muons are reconstructed to estimate the initial direction of muon neutrinos and muons. Since muons propagate long distances before the detector entry, the deflection of the muon while the propagation has to be studied to estimate if the deflection has to be considered as a systematic uncertainty for the angular muon reconstruction.

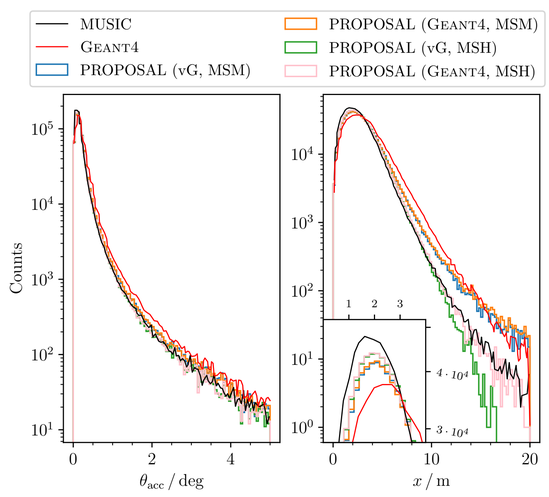
Methodology

The lepton propagator PROPOSAL [1], maintained in Dortmund, is used to simulate the muon deflection. The tool provides different methods for multiple scattering and deflections by stochastic interactions are implemented recently. To estimate the deflections for neutrino telescopes such as IceCube or KM3NeT, muons are propagated through ice and water with different energies.

Good Agreement with MUSIC and GEANT4

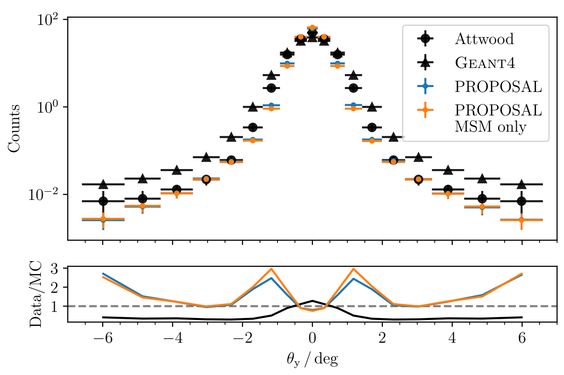
Other common tools to simulate particles through matter are MUSIC [2] and GEANT4 [3]. Here, 1 Mio. muons are propagated with energies of 2 TeV through water over a distance of 3 km. PROPOSAL provides deflection parametrizations of GEANT4 and Van Ginneken (v.G.) as well as scattering methods by Molière (MSM) and Highland (MSH).

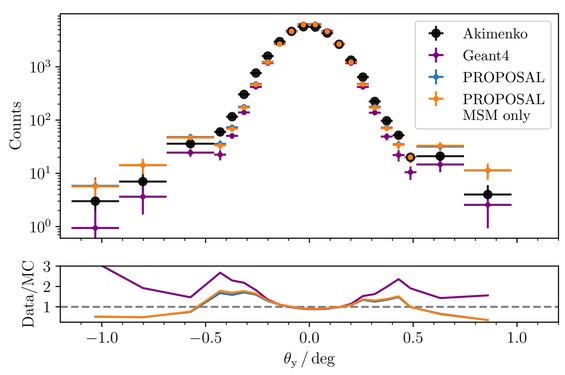
- Good agreement in angular deflection
- Small deviations in lateral displacement x
- GEANT4 and PROPOSAL using Molière scattering lead to largest displacements
- Larger displacements are caused by large deflections occurring at the beginning of the propagation



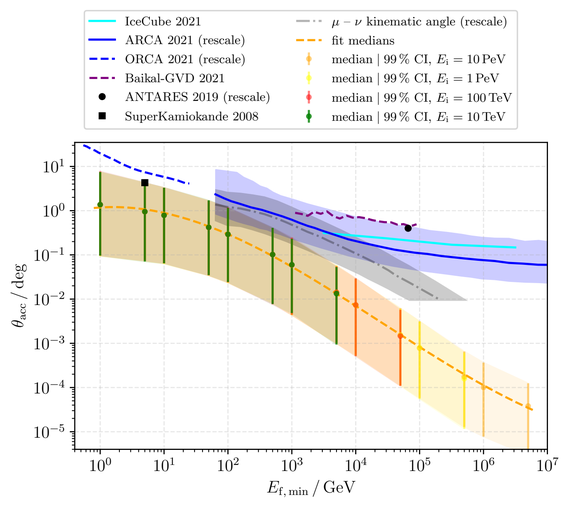
Good Data-MC Agreements

Muon deflection measurements are performed by Attwood for muons propagated with energies of 199 MeV through 109 mm liquid hydrogen and by Akimenko for muons propagated with energies of 7.3 GeV through 1.44 cm copper. The deflections simulated with PROPOSAL are in good agreement with the data.





Muon Deflection Impact on Current Experiments



Muons are propagated through ice with several initial energies to different final energies. The lower the final energy, the larger the muon deflection. Since the medians overlap for different initial energies, the total muon deflection is nearly independent of the initial energy. Thus the muon energy reconstructed at the detector entry can be used to estimate the muon deflection before the entry.

All medians are fitted by a polynomial which can be used to estimate the muon deflection as a function of the final muon energy. The function can be found in Ref. [4]. (The deviations of the muon deflection for a propagation in water are less than 1 % for all energies.)

Relevance for Muography

Muography is a technique to analyze the inner structures of vulcanoes, pyramids, mines and much more. Muons produced in the atmosphere are measured and due to different densities, the muon flux differentiates in front of and behind an object. The angular resolution of these detectors is about 0.6 °, wich is on the order of magnitude of the muon deflection at GeV energies.

Conclusion

Muon deflections simulated with the propagation tool PROPOSAL are in good agreement with common simulation tools MUSIC and GEANT4 and two measurements. For muon energies below 3 TeV, the muon deflection is on the same order of magnitude as the kinematic scattering angle between the incoming neutrino and the produced muon. In comparison with angular resolutions of current muon detectors, the muon deflections become relevant for energies below 1 TeV.

Future Research

So far, muon deflections are measured only for energies of 7.3 GeV and lower. To approve the correctness of the simulated muon deflection for higher energies, measurements of muons with energies up to TeV or even PeV are required. Furthermore, the muon deflection has to be considered if the angular resolutions increase in future experiments and optimizations.

The lepton propagation tool PROPOSAL is available at github.com/tudo-astroparticlephysics/PROPOSAL.

References

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Note: All figures are taken from Ref. [4].

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