

Koehne, J.-H.; Frantzen, K.; Schmitz, M.; Fuchs, T.; Rhode, W.; Chirkin, D.; Becker Tjus, J.

PROPOSAL: a tool for propagation of charged leptons. (English) Zbl 1344.81146
Comput. Phys. Commun. 184, No. 9, 2070-2090 (2013).

Summary: The search for astrophysical high-energy neutrinos is one of the most important approaches to pin-point the sources of cosmic rays. The advantage of using these neutral and only weakly-interacting particles as messengers in order to look deep into the sources themselves is at the same time the main challenge, as extremely large detectors are needed to measure a significant signal. With the finalization of the large underground detectors IceCube and ANTARES, the quantity and the quality of the recorded data are now at a stage where many analyses have a sensitivity limited by the systematic error rather than statistical uncertainties. Such an error source is the Monte Carlo description of the lepton energy losses before a lepton reaches the detector and of all leptons within the detector. A very accurate simulation of the propagation of muons through large amount of matter is needed because a muon may sustain hundreds of interactions before it is detected by the experiment. Requirements on the precision of the muon propagation code are very stringent. A stochastic correct description of the series of lepton interactions within the detector is needed for a correct conclusion from the measured signature to the lepton energy respectively neutrino energy. In this paper, the Monte Carlo code PROPOSAL (Propagator with optimal precision and optimized speed for all leptons) is presented as a public tool for muon propagation through transparent media. Up-to-date cross sections for ionization, bremsstrahlung, photonuclear interactions, electron pair production, Landau-Pomeranchuk-Migdal and Ter-Mikaelian effects, muon and tau decay, as well as Molière scattering are implemented for different parametrizations. Thus, a full study of the systematic uncertainties is possible from the theoretical description of lepton energy loss in the context of high-energy neutrino analyses and other astroparticle physics experiments that rely on the proper description of lepton propagation. A numerical precision of better than 10^{-6} is achieved, setting the systematic error for high-energy neutrino analyses to a minimum from the numerical prospective.

MSC:

81T80 Simulation and numerical modelling (quantum field theory) (MSC2010)
85A25 Radiative transfer in astronomy and astrophysics

Keywords:

Monte-Carlo simulation; muon interaction; icecube

Software:

PROPOSAL

Full Text: [DOI](#)

References:

- [1] Becker, J. K., *Physics Reports*, 458, 173, (2008)
- [2] Kelner, S. R.; Aharonian, F. A.; Bugayov, V. V., *Physical Review D*, 74, 3, 034018, (2006)
- [3] Kelner, S. R.; Aharonian, F. A., *Physical Review D*, 78, 3, 034013, (2008)
- [4] *Nuclear Instruments and Methods in Physics Research A*, 524, 169, (2004)
- [5] *Astrophysical Journal*, 745, 45, (2012)
- [6] *Nuclear Instruments and Methods in Physics Research A*, 656, 11, (2011)
- [7] Distefano, C., *Nuclear Physics B Proceedings Supplements*, 190, 115, (2009)
- [8] R. Abbasi, Y. Abdou, T. Abu-Zayyad, et al. arXiv:1202.4564 [e-prints], February 2012.
- [9] *Astroparticle Physics*, 35, 634, (2012)
- [10] W. Lohmann, R. Kopp, R. Voss, CERN 85-03, p. 29, March 1985.
- [11] Lipari, P.; Stanev, T., *Physical Review D*, 44, 3543, (1991)

- [12] Desiati, P., International Cosmic Ray Conference, 3, 985, (2001)
- [13] D. Chirkin, W. Rhode, arXiv:hep-ph/0407075, July 2004.
- [14] Groom, D.; Klein, S., The European Physical Journal C - Particles and Fields, 15, 163, (2000)
- [15] B.B. Rossi, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1954.
- [16] Groom, D. E.; Mokhov, N. V.; Striganov, S. I., Atomic Data and Nuclear Data Tables, 78, 183, (2001)
- [17] R.P. Kokoulin, A.A. Petrukhin, S.R. Kelner, Moscow Engineering Physics Inst., Moscow, 1995 (preprint).
- [18] Bethe, H.; Heitler, W., Royal Society of London Proceedings Series A, 146, 83, (1934) · [Zbl 60.1455.06](#)
- [19] Bethe, H., Proceedings of the Cambridge Philosophical Society, 30, 524, (1934) · [Zbl 0010.22909](#)
- [20] Petrukhin, A. A.; Shestakov, V. V., Canadian Journal of Physics, 46, 377, (1968)
- [21] Andreev, Y. M.; Bezrukov, L. B.; Bugaev, E. V., Physics of Atomic Nuclei, 57, 2066, (1994)
- [22] Bezrukov, L. B.; Bugaev, E. V., International Cosmic Ray Conference, 7, 102, (1981)
- [23] Sokalski, I. A.; Bugaev, E. V.; Klimushin, S. I., Physical Review D, 64, 7, 074015, (2001)
- [24] Tsai, Y.-S., Reviews of Modern Physics, 46, 815, (1974)
- [25] Bethe, H. A.; Maximon, L. C., Physical Review, 93, 768, (1954)
- [26] Kelner, S. R.; Kokoulin, R. P.; Petrukhin, A. A., Physics of Atomic Nuclei, 60, 576, (1997)
- [27] Bezrukov, L. B.; Bugaev, E. V., Soviet Journal of Nuclear Physics, 33, 1195, (1981)
- [28] Bugaev, E. V.; Shlepin, Y. V., Nuclear Physics B Proceedings Supplements, 122, 341, (2003)
- [29] Bugaev, E.; Montaruli, T.; Shlepin, Y.; Sokalski, I., Astroparticle Physics, 21, 491, (2004)
- [30] Kokoulin, R. P., Nuclear Physics B Proceedings Supplements, 70, 475, (1999)
- [31] Rhode, W., Nuclear Physics B Proceedings Supplements, 35, 250, (1994)
- [32] Derrick, M., Zeitschrift für Physik, C63, 391, (1994)
- [33] H. Abramowicz, A. Levy, arXiv:hep-ph/9712415, December 1997.
- [34] Abramowicz, H., Physics Letters B, 269, 465, (1991)
- [35] Iyer Dutta, S., Physical Review D, 63, 9, 094020, (2001)
- [36] Badełek, B.; Kwieciński, J., Reviews of Modern Physics, 68, 445, (1996)
- [37] Whitlow, L. W., Physics Letters B, 250, 193, (1990)
- [38] B. Badelek, J. Kwiecinski, A. Stasto, arXiv:hep-ph/9603230, March 1996.
- [39] Capella, A., Physics Letters B, 337, 358, (1994)
- [40] Butkevich, V.; Mikheyev, S. P., Soviet Journal of Experimental and Theoretical Physics, 95, 11, (2002)
- [41] Kelner, S. R.; Kotov, Yu. D., Soviet Journal of Nuclear Physics, 7, 237, (1968)
- [42] Kokoulin, R. P.; Petrukhin, A. A., (International Cosmic Ray Conference, International Cosmic Ray Conference, vol. 4, (1970)), 277
- [43] R.P. Kokoulin, A.A. Petrukhin, Proceedings of 12th International Conference on Cosmic Rays, p. 2436, 1971.
- [44] Kelner, S.; Kokoulin, R.; Petrukhin, A., Physics of Atomic Nuclei, 63, 1603, (2000)
- [45] Klein, S., Reviews of Modern Physics, 71, 1501, (1999)
- [46] Migdal, A. B., Physical Review, 103, 1811, (1956)
- [47] Polityko, S., Journal of Physics G Nuclear Physics, 28, 427, (2002)
- [48] Polityko, S., Nuclear Instruments and Methods in Physics Research B, 173, 30, (2001)
- [49] Stanev, T., Physical Review D, 25, 1291, (1982)
- [50] Ternovskii, F., Soviet Physics - JETP, 37, (1960)
- [51] Lynch, G. R.; Dahl, O. I., Nuclear Instruments and Methods in Physics Research B, 58, 6, (1991)
- [52] Mustafa, A. A.M.; Jackson, D. F., Physics in Medicine and Biology, 26, 461, (1981)
- [53] Butkevich, A. V., Nuclear Instruments and Methods in Physics Research A, 488, 282, (2002)
- [54] Press, W. H, Numerical recipes, (1988), Cambridge University Press
- [55] W. Rhode, C. Carloganu, DESY-PROC-1999-01, 1999.
- [56] F. Schröder, W. Rhode, H. Meyer, 27th International Cosmic Ray Conference, Hamburg, 2001.
- [57] Ahlen, S. P., Reviews of Modern Physics, 52, 121, (1980)
- [58] Wick, S. D., Astroparticle Physics, 18, 663, (2003)
- [59] Antonioli, P., Astroparticle Physics, 7, 357, (1997)
- [60] Lipari, P., Astroparticle Physics, 1, 195, (1993)
- [61] Review of particle physics, European Physical Journal C, 15, 1, (2000)

[62] Kelner, S. R.; Kokoulin, R. P.; Petrukhin, A. A., *Physics of Atomic Nuclei*, 62, 1894, (1999)

[63] H. Abramowicz, *Private communication*, 2001.

[64] Saji, C.; Butkevich, A. V.; Mikheyev, S. P., *International Cosmic Ray Conference*, 3, 1471, (2003)

This reference list is based on information provided by the publisher or from digital mathematics libraries. Its items are heuristically matched to zbMATH identifiers and may contain data conversion errors. It attempts to reflect the references listed in the original paper as accurately as possible without claiming the completeness or perfect precision of the matching.