

To make a scientific discovery, usually something has to go wrong first. As we develop our understanding of Nature, it is getting harder and harder to find the next crack. This time is about a crack in the mirror, the mirror between matter and antimatter. We do not know why there is more matter than antimatter in the Universe, but we have a guess. It seems that the missing piece can be brought but the most mysterious carriers—neutrinos.

For many years, scientists all over the World, have built enormous detectors to catch at least a few of these elusive particles. Finally, we have learned how to make neutrino factories and we can focus on revealing their secrets. We know that they appear in three types (electron, muon, tau neutrinos) and that they have a very small mass. Surprisingly, we discovered that within some distance they can morph between the types—an effect known as neutrino oscillation. This leads us to our crack in the mirror: do they morph the same way in a reflected image of our World? If so, it means that neutrinos can provide a mechanism to break the matter-antimatter balance in the Universe that after billions of years resulted in our matter-filled World.

To prove this theory, we try to measure their interactions far away from the source: giving them a little space to oscillate. Still, many experimental inconveniences call theoretical physicists for help. To learn from neutrinos behavior, we need to think like neutrinos: simulate their interactions with matter. We do this using the so-called Monte Carlo neutrino event generators that use most of our current knowledge. If measurements do not align with our expectations, we see that we need to learn more. However, details matter. By building larger and more advanced detectors we slowly step into the precision era of neutrino measurements. Soon, good simulations will be not enough, they will have to be excellent. We plan to make one more step towards reliable Monte Carlo predictions.

We usually model neutrino interactions just like a break shot in the game of billiards: neutrino being a cue ball and a triangle of other balls being an atomic nucleus. Sometimes if you strike one ball, the others might not notice it, but sometimes if you hit hard enough, you can move them all. Neutrino experiments only follow the cue ball after the break and from this knowledge they try to figure out how hard the ball was shot. In this analogy, nothing that happens to the colorful balls matters. But the quantum mechanics does not work like this. Here, everything matters.

In the quantum world, the cue and the struck ball remember each other, and everything that happens to the colorful ball later will make the white change its speed and direction too. We want to allow our Monte Carlo event generators to be able to reproduce this behavior. However, such a qualitative difference requires developing new techniques for handling the theoretical models. Reshaping our understanding of modeling neutrino interactions in Monte Carlo event generators is the main goal of this project.

Many sophisticated neutrino interaction models exist, but not many find their way into the experimental analyses. As a physicist, R. Feynman, once said: *It doesn't matter how beautiful your theory is, it doesn't matter how smart you are. If it doesn't agree with experiment, it's wrong.* Therefore, we need to continue the effort of supporting neutrino experiments with the best Monte Carlo generators to validate the theoretical knowledge. Repeating this process brings us slowly to understand the nonintuitive behavior of neutrinos better. Soon this crack in our understanding of Nature will be filled and then we will search for a new one.