A Modern Toolkit to Understand the Visible Universe

One of the most challenging questions in contemporary physics is to understand why our visible Universe consists of so much more matter than antimatter. According to the present paradigm, equal amounts of matter and antimatter should have been created in the Big Bang. Yet, we clearly consist of matter. What happened to the antimatter?

If particles and antiparticles follow slightly different physical laws, it is possible that particles (matter) over time have been enriched with respect to antiparticles (antimatter). This process is referred to as *Baryogenesis* [1]. But how do these physical laws look like? The Standard Model of particle physics describes the elementary particles and their interactions. It has been rigorously and immensely successfully tested in experiments since the mid-seventies. However, the differences in the interactions by particles and antiparticles predicted by the Standard Model would result in a matter-antimatter asymmetry that is about 10 000 000 times smaller than the observed one [2]. Does this mean there is something beyond the Standard Model?

A unique key to this puzzle is offered by *hyperons.* Hyperons are heavier and unstable siblings of the protons and neutrons. When hyperons decay, the reveal their inner "magnet", *i.e.* their spin, which in turn is sensitive to the processes that could lead to Baryogenesis. Hyperons and antihyperons can be produced in electron-positron colliding experiments such as BESIII in China [3] and Belle II [4] in Japan, and in the future antiproton-proton experiment PANDA in Germany [5]. The hadron physics group in Uppsala has developed a formalism for the production and decay of hyperon-antihyperon pairs [6], implemented in C++ and proven to be a powerful tool in the studies of Λ hyperons [7,8]. A faster, more user-friendly and maintainable tool for parameter estimation has recently been implemented in python in the BSc thesis by Benjamin Verbeek [9]. The just-in-time compiler Numba increased the analysis speed by a factor of 400 compared to regular python code.

This project aims to creating a complete toolkit to facilitate future searches for discrepancies between matter and antimatter. This includes a new Monte Carlo generator to simulate the hyperon-antihyperon production and subsequent decay as well as extensions of Verbeek's parameter estimation tool. To ensure fast run-times also for the very large data sets required in this field of research, computational speed should be a consideration from the start. Furthermore, parts of the toolkit are intended to be offered as cloud-based services. Therefore, we will explore scalability through parallelization on both local and distributed computing resources.

References:

[1] A. D. Sakharov, Pisma Zh. Eksp. Teor. Phys. Fiz. 5, 32 (1967).
[2] W. Bernreuther, Lect. Notes Phys. 591, 237 (2002);
[3] BESIII Collaboration, Nucl. Instrum. Meth. A 614, 345 (2010).
[4] Belle II Collaboration, Belle II Technical Design Report, arXiv:1011.0352 (2010).
[5] PANDA Collaboration, PANDA Technical Progress Report, FAIR-ESAC (2005).
[6] G. Fäldt and A. Kupsc, Phys. Lett. B 772, 16 (2017).
[7] BESIII Collaboration: Phys. Rev. Lett. 123, 122003 (2019);
[8] BESIII Collaboration, Nature Phys. 15, 631 (2019).
[9] B. Verbeek, *Maximum Likelihood Estimation of Hyperon Parameters in Python: Facilitating Novel Studies of Fundamental Symmetries with Modern Software Tools,* Bachelor Thesis, Uppsala University (2021)