Referee report on the Ph.D. thesis of Nora Salone
"Properties of Hyperon Decays"

Mainz, September 10, 2024

Ms. Salone's thesis deals with the study of violation of the charge-parity (CP) symmetry where the hyperons, alongside with the kaons, are an important and long appreciated tool. Since searches for violation of fundamental symmetries in atomic, nuclear and particle physics are ongoing along several fronts, the topic of this study is of prime importance. The work reported in this thesis is applied to the existing and future facilities, and the results seem encouraging: they demonstrate that adding the electron beam polarization in an e^+e^- machine will allow for a significantly improved sensitivity to CPV signatures.

The task of judging a work carried out during a Ph.D. entails assessing the quality of the research, that of the description of the tools and methods used, and of the presentation of the results. Since the Ph.D. is a launching ramp for a young colleague into the world of the independent research, also the depth of the candidate's understanding of fundamental physics concepts, the command of the tools used and the innovativeness in applying them need to be addressed. For an external referee who only largely sees the dissertation and the published articles, this information is certainly not enough for a complete assessment of all these criteria. With a full realization of these shortcomings, I offer below my assessment of Ms. Salone's dissertation.

1. *The structure of the dissertation*. The dissertation contains 4 chapters: an introduction (Chapter 1, 21 pages), a Summary (Chapter 4, 3 pages) and Chapters 2 and 3 that are published works co-authored by Ms. Salone (some 80 pages together). The last 10 pages of the dissertation are references. It is a little unusual for a Ph.D. thesis to directly copy the published works in the middle of the dissertation and accompany them with an introduction and a summary. Such a format may be more appropriate for a habilitation as the latter often contains more (and more disconnected among themselves) articles that are harder to incorporate into a coherent text. Of course, the candidate decided to follow this format together with her Ph.D. advisor, so I do not doubt that the two articles were largely written by Ms. Salone, beyond being based upon her work. The Section 1.4 is dedicated to stating the candidate's contribution; I find it unfortunate that the contributions mentioned in that part only concern the technical aspects of the work, and not the writing. This is a pity because Chapters 2 and 3 read well, in a good English and with a nice introduction for a broader audience followed by considerable details needed by the experts. Since these articles were peer-reviewed and published in Phys. Rev. D, a judgement from me is superfluous.
2. *Quality of the presentation*. Communicating one's research to peers (and to funding agencies) is an important part of our work. As explained above, I refrain from assessing the quality of the presentation in Chapters 2 and 3 and limit myself to

discussing the Introduction and Summary. The Introduction, after a brief foreword, consists of two roughly equal parts, a historical introduction to the Standard Model (1.1), and some basics of the hyperon phenomenology and CP violation (1.2 and 1.3). The historical part is well written and is an easy read. My only remark concerns some references. Wu's experiment was directly motivated by Lee and Yang's paper which introduced all possible structures, including V-A, and for the first time conjectured a possibility of P-violation, which earned the two the Nobel prize. Glashow is listed alongside Weinberg and Salam with whom he shared the Nobel prize but is not cited. Ref. [24] certainly deals with confinement but is neither the first, nor the most cited one. A search on inspires returns a 1974 paper "Confinement of Quarks" by Wilson, also a Nobel prize winner, cited 6,406 times. In 1.2-3 the story goes over to the hyperon phenomenology. It is clear the candidate possesses the material quite well. What concerns the big picture is however again less convincing: the claim that searches for CPV span over direct and indirect as described on p.17 ignores the searches for the electric dipole moment (EDM) of neutrons and electrons, the strong CP problem and many other points, and only mentions kaons and hyperons. Section 1.4 lists the Candidate's contributions. It is clear and largely compensates for the shortcomings of the structure of the dissertation (in the eyes of this reviewer), except for lacking the mention of the contribution to writing the articles, as stated already. Chapter 4 offers a summary and an outlook of the presented research. It is very clear and concise; the outlook reads very promising. A bigger picture is touched only slightly by mentioning the applicability of the formalism developed in this thesis to charmed baryons at the LHC. However, even the mentioned applications will require a dedicated effort and will benefit the existing and upcoming experimental programs.

3. *Quality of research*. It is clear that the research reported in Chapters 2 and 3 is high quality. It qualifies, according to the methods used, as phenomenological. Section 2.2 contains a thorough overview of the state-of-the-art phenomenology of CP tests with hyperons which I found quite useful for my own information. Section 2.3 presents the formalism that extends the existing one by including the left- or right-handed polarization of the electron beam. Its effect on the hyperon polarization is clearly displayed in Fig. 2.3. All details needed to analyze the hyperon pair production at the J/ψ resonance and their subsequent decay are given and applied to specific experimental conditions with special attention to the uncertainty quantification. Figs. 2.14,15 then convey the main message: adding an explicit P-odd signature, the electron helicity, boosts the sensitivity to P- and CP-odd effects which are thus less prone to being diluted by experimental uncertainties. Chapter 3 extends the consideration to semileptonic decay modes which are more complicated than the hadronic ones, both due to the 3-body final state and a more complicated structure of the decay amplitudes. Joint angular distributions for spin-entangled hyperon-antihyperon pairs are constructed, such that parameters of the hyperon weak form factors can be extracted. The benefit of controlling the decaying hyperon (e.g., by including the electron beam polarization in e^+e^- collider) is less pronounced in this case

4. *Conclusion*. I have reviewed the doctoral thesis by Ms. Salone. I deem that she delivered impressive results and developed, under the guidance of her advisors, a valuable and versatile tool that is readily being used for the analysis of the ongoing experiments on the resonant J/ψ production of hyperon-antihyperon pairs with the scope of addressing CP violation in strange hadrons alternative to kaons. The future facilities may considerably improve the existing limits if, additionally to higher luminosity, the beam polarization is implemented, according to the findings obtained in this thesis. It would be interesting to understand, whether hyperon SL decays may become a competitive source of the CKM matrix element Vus in the near future. Apart from minor critical comments that only refer to the presentation and layout of the dissertation, I evaluate the Ph.D. thesis of Ms. Salone very positively.

Sincerely, Mikhail Gorshteyn