FLAP (Facility for Low-energy Antineutron Physics)

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1. Research objectives

We propose a case study aiming to the development of a novel low-energy antineutron beamline at CERN's Antiproton Decelerator (AD), to enable precision measurements of antineutron–proton and antineutron–nucleus scattering at unprecedented low energies, down to less than 10 MeV/c. The current knowledge of low-energy antinucleon interactions is limited by the scarcity of experimental scattering data in the low energy regime; moreover, existing data are aged as the latest studies with antineutrons as probes date back to the 1990s, and ceased following the closure of the LEAR facility at CERN.

The study of antinucleon–nucleon interactions plays a unique role in the investigation of hadron–hadron interactions. Compared to antiprotons, antineutrons have the advantage of being free from Coulomb scattering. Moreover, isospin selection helps reduce the number of partial waves involved in the annihilation process. Nevertheless, several of the observations on annihilation dynamics performed so far are still waiting for a comprehensive explanation. For instance, precise and model-independent measurements of quantities like the S-wave scattering length are still certainly needed to provide a strong constraint to antinucleon–nucleon interaction models, which to-date rely primarily on low-energy antiproton-proton cross sections and protonium X-ray measurements. Regarding the interaction of antineutrons with nuclei, the scattering parameters are still scarcely known but they are essential to improve the sensitivity in future neutron–antineutron oscillation searches, whose design is presently ongoing at the ESS facility in Sweden.

To produce antineutrons, an antiproton beam with at least 100 MeV/c momentum is needed. The approach we propose[1] exploits the center-of-mass backward-angle charge-exchange (CEX) production ($\bar{p}p \rightarrow \bar{n}n$) with 300 MeV/$c$ antiprotons, and stands as an element of novelty compared to past forward-angle production schemes. Although the backward production cross section is significantly low, at 300 MeV/c antineutrons with momenta as low as 9 MeV/c in the laboratory frame can be produced. Preliminary calculations show that a yield of approximately one antineutron per AD cycle, containing 5×10^7 fast extracted antiprotons every 120 s, can be expected, sufficient for percent-level precision scattering cross section measurements within one week.

One of the project's tasks is to perform feasibility tests of this approach within the existing AD complex. In the CEX reaction, predominantly center-of-mass forward antineutrons will be produced, mixed with a small fraction of low-energy backward ones; in the laboratory frame they are emitted close to zero degrees, and are distinguishable by their longer time-of-flight. Their detection will be performed through a suitable antineutron detector, located downstream of a bending dipole magnet. Preliminary GEANT4-based simulations of a tentative set-up geometry indicate that all the background contributions remain at acceptable levels.

A possible future implementation of the slow antiproton extraction mode could provide an antineutron beam with a broader continuous energy spectrum. This option would extend the accessible physics reach, opening new physics opportunities for further insight into many still unsolved issues. Moreover, antiprotons delivered via slow extraction could enable precise measurements of antiproton cross-sections on previously unexplored nuclear targets, several of which hold particular relevance for cosmic ray studies: antiprotons as cosmic rays could act as messengers in Dark Matter searches, and their flux can provide strong bounds on a variety of Dark Matter models.

[1] Letter of Intent submitted to CERN SPSC, May 1, 2025: https://cds.cern.ch/record/2930906

Therefore, the project potentially promises significant advancements in the understanding of low-energy antinucleon interactions, with broad implications for nuclear physics, astrophysics and fundamental symmetry studies.

2. Connection to Transnational Access infrastructures (Tas) and / or Virtual Access projects (Vas)

Currently, the AD facility at CERN (the TA infrastructure in this project) is capable of delivering spills of 100 MeV/c fast extracted antiprotons to the ELENA ring every two minutes. At the AD, fast extraction at higher momenta (300 and 502 MeV/*c*) was already successfully demonstrated. Accelerator experts confirmed that both high-momentum and slow extraction could be incorporated into a future upgrade of the AD. While the implementation of the slow extraction feature would require significant modifications to the existing infrastructure, the challenge is considered, in principle, as technically feasible. If realized, such an upgrade could enable long spills with an intensity comparable to what had been previously provided by LEAR. Such an intense beam of up to 3.5 GeV/*c* antiprotons would therefore stand out as the asset of a general purpose facility for novel hadronic physics experimentations.

Given the scientific potential of antineutron studies and the precedent of successful antiproton exploitation at various energies, targeted investment in slow extraction at high-momentum capabilities at the AD would represent a timely and strategic enhancement to CERN antimatter research infrastructure.

We hereby propose a case study, to be carried out mainly by dedicated postdoctoral researchers, with the objective of proving the feasibility of the described approach, and establishing the experimental parameters required for the development of a versatile facility applicable to a broad spectrum of experiments. This activity would result in the preparation of a Proposal and could constitute the groundwork for a future, complete Technical Design Report. In parallel, the Collaboration could also take care of developing a repository to store and critically organize all relevant existing data on low-energy antineutron and antiproton interactions in a dedicated web site, that would serve as a reference benchmark for future studies involving the interaction of these particles. This could be of relevance also to high energy physics experiments, as those observing possible baryonium states close to the nucleon-antinucleon threshold, in charm and heavier quark systems decays, and would allow Virtual Access to the existing, and future, data.

3. Allocated budget: total 120 k€

- Term position(s) for Post-Doctoral collaborator(s), working on the study of low-energy antineutron production feasibility with fast extracted beam and on the design of a slow extraction beam-line: 120 k€ (including 25% overhead).

4. Participating and partner institutions

- Department of Physics, Institute of Science Tokyo (JP);
- Dipartimento di Fisica, Università degli Studi di Torino (IT);
- Dipartimento di Ingegneria dell'Informazione, Università degli Studi di Brescia (IT);
- Institute for Integrated Radiation and Nuclear Science, Kyoto University (JP);
- Istituto Nazionale di Fisica Nucleare [PV, TO] (IT);
- Stefan Meyer Institute for Subatomic Physics, Austrian Academy of Sciences (AT);
- Trento Institute for Fundamental Physics and Applications (IT).