"International Network for Challenges of a Spin Physics Hadron Storage Ring (INCH)"

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1. Research objectives: Making use of the polarization degree of freedom in hadron interactions offers new observables to test fundamental symmetries like parity (P), time reversal (T) and charge conjugation (C) or combinations thereof with exciting science cases. One example is Electric Dipole Moments (EDMs), which violate P and T and, via the CPT theorem, also CP. This violation is deemed necessary to explain the baryon asymmetry of the universe. Complementary to EDMs, double polarized elastic proton-deuteron scattering tests P violating and T conserving interactions. Experiments with polarized hadron beams also allow to search for the axion or axion like particles (ALPs) as a possible originator of Dark Matter.

Pioneering work on all of these issues was done by the JEDI Collaboration at the COSY storage ring at FZ-Jülich. The collaboration has, e.g., successfully conducted the first ever measurements of both static and oscillating EDMs [1] of the deuteron in a magnetic storage ring (references), thereby demonstrating the viability of storage ring technology for precision spin physics. Going beyond COSY, the forthcoming phase of the research involves the design and later on the construction of a dedicated precision storage ring.

The main technological challenge is to provide and maintain highly polarized hadron beams and targets. In this LOI, we propose the INCH network within the HADRON… to address the following concrete tasks to meet these challenges:

1) **Beam intensity: optimizing beam transport and injection efficiency with ML tools**

   For this project high-intensity polarized beams are mandatory. Therefore the transportation of the beam from the polarized source to the storage ring and its injection have to be optimized. This task is well suited for machine learning algorithms since a target quantity (beam intensity) depends on hundreds of parameters (magnet settings). First successful applications of corresponding techniques at COSY [2,3] employing Bayesian Optimization and Reinforcement Learning algorithms will be further studied.

2) **Spin Coherence Time: providing long SCT of the stored polarized beam**

   Spin rotations caused by machine imperfections on particles with a magnetic dipole moment lead to decoherence of the in-plane polarization. Extending spin coherence involves using bunched beams and sextupole magnets to reduce decoherence from betatron and synchrotron oscillations. The JEDI collaboration reached deuteron SCTs of over 1000 s routinely at COSY [4]. Obtaining such times for protons will be much more difficult because of the larger magnetic moment. Based on the COSY experience simulations studies on how to achieve large SCTs also for protons will be conducted.

Approach

Both tasks employ simulations and machine learning tools leading to a design of a new type of high precision storage ring. This will be done in a cooperation with international partners (see below) with the corresponding expertise.

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

- Achieving the objectives of the INCH project necessitates a strong collaborative framework among INFN, CERN, RWTH, GSI, and BNL.
- INFN, RWTH, IKP of FZ-Jülich (now under the administrative oversight of GSI), and CERN have already played a pivotal role in the successful experimental developments at the COSY storage ring, clearly demonstrating the effectiveness of international cooperation.
- In the current context, it is essential to strengthen ties with U.S. partners, who are likewise engaged in addressing the fundamental questions at the heart of this research.

3. Estimated budget: 150 k€

- 1 Postdoc for two years for INFN-FE: 100 k€
- Travel expense for INFN-FE: 25 k€
- Travel expenses for RWTH - Aachen: 25 k€

4. Participating and partner institutions

- INFN - Ferrara (P.L. Coordinator)
- RWTH - Referent person: J. Pretz
- GSI – Referent persons: Y. Litvinov/R. Assmann
- CERN – Referent person: C. Carli
- BNL – Referent persons: Y. Semertzidis/F. Rathmann

[1] First Search for Axionlike Particles in a Storage Ring Using a Polarized Deuteron Beam, S. Karanth et al., *Phys.Rev.X* 13 (2023) 3, 031004

[2] Optimization of the injection beam line at the Cooler Synchrotron COSY using Bayesian Optimization, A. Awal et al., *JINST* 18 (2023) 04, P04010

[3] Injection optimization at particle accelerators via reinforcement learning: From simulation to real-world application, A. Awal et al., *Phys.Rev.Accel.Beams* 28 (2025) 3, 034601

[4] How to Reach a Thousand-Second in-Plane Polarization Lifetime with 0.97-GeV/c Deuterons in a Storage Ring, JEDI Collaboration, G. Guidoboni et al, *Phys.Rev.Lett.* 117 (2016) 5, 054801