Letter of Intent

IR4spin

Spin Physics at LHC Interaction Region 4

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1. Research objectives

The goal of the IR4spin project is to develop innovative technologies for measuring the 3D structure of nucleons, collective phenomena, and the deep structure of hadrons through high-energy polarized fixed-target collisions at the LHC.

To describe the structure of nucleons, the particle physics community has traditionally focused on two main quantities: the spatial distribution of electric charge and magnetic moment, probed through elastic lepton-nucleon scattering and described by the Electric and Magnetic Form Factors (FFs), and the longitudinal momentum distributions of partons, described by the collinear parton distribution functions (PDFs). While both FFs and PDFs have significantly shaped our physical picture of the nucleon, they provide only partial information about its internal structure. FFs lack information on partonic dynamics, while collinear PDFs offer no insight into their spatial distributions and transverse motion. In the last decades, a breakthrough has come from accessing the nucleon's full 3D structure through observables sensitive to either Generalized Parton Distributions (GPDs) or Transverse Momentum Dependent parton distribution functions (TMDs). Particularly relevant in the contemporary context is the measurement of heavy-quarks observables sensitive to the largely unknown gluon TMDs, such as, e.g., the unmeasured gluon Sivers function. This function provides valuable information about the spin-orbit correlations of gluons inside the nucleon and is sensitive to the unknown gluon orbital angular momentum.

Despite impressive theoretical progress, making precise predictions for nucleon structure from first principles remains a formidable challenge, and detailed experimental measurements are crucial for progress in this field. This challenge has motivated numerous past experiments and serves as a core principle for proposals of new-generation experimental facilities worldwide.

This IR4spin project will explore new processes and novel probes in a unique, and previously unexplored, kinematic regime. Specifically, a beam at the TeV scale allows to access the large negative Feynman x_F and high Bjorken-x regions at intermediate Q^2, using beam-gas collisions at $\sqrt{s_{NN}}$~100 GeV. Since direct polarization of the LHC beam is not feasible, this method constitutes the only possibility to explore this new frontier and maximize the scientific return from the LHC.

Additionally, IR4spin proposes an unprecedented opportunity: the possibility of merging the LHC heavy-ion program with spin physics, enabling, for the first time, studies of polarized lead-proton and lead-deuterium collisions at high energy. The use of a polarized gaseous fixed-target presents several unique advantages: (i) high polarization degree (up to 85%); (ii) no dilution effects due to the presence of unpolarized materials in the target; (iii) fast polarization direction flipping to reduce systematic effects; (iv) relatively high luminosities with sufficiently dense targets; (v) precise determination of the beam-gas luminosity; (vi) negligible effects on the beam life-time; (vii) possibility to also inject unpolarized gases.

This ambitious task demands the development of a next-generation apparatus, including a polarized pure molecular hydrogen/deuterium gas target, and an absolute polarimeter to be operated within the world's most advanced collider environment. The project builds upon the successful installation and operation of SMOG2, an unpolarized gas target installed upstream of the LHCb spectrometer, a successful project part of the EU-Strong H2020 previous EU funding program. Since LHC Run3, SMOG2 has been collecting fixed-target high statistic data with minimal impact on beam operation.

LHC Interaction Region 4 (IR4), a straight section of the collider, offers a suitable place to develop, test and commission this new experimental setup, enabling also early-phase physics measurements. Then, in a second phase, as already mentioned in the Scoping Document of the LHCb detector Upgrade-II, the polarized system can be moved and implemented into the LHCb spectrometer to fully exploit its capabilities.

At this end, IR4spin represents a realistic and cost-effective opportunity to implement and install a polarized gaseous hydrogen (protons) or deuterium (protons and neutrons) target within an existing, high-performance accelerator such as LHC, in a relatively short timeframe.

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

Achieving IR4spin's objectives requires a collaborative bridge between CERN and INFN Laboratori Nazionali di Frascati. At INFN, in close collaboration with the University of Ferrara, a new generation of polarized setup will be developed. This will include advanced surface coating technologies, also relevant for future accelerators, and a compact Atomic Beam Source optimized using Machine Learning techniques. A key deliverable will be the development of an absolute polarimeter based on the Coulomb Nuclear Interference (CNI) scattering. The availability of the Beam Test Facility at LNF is a major advantage for characterizing the recoil detectors. At CERN, successful implementation within the High Luminosity LHC environment will require dedicated studies, including impedance modeling and beam dynamic calculations, as well as studies connected to the vacuum condition modification.

3. Estimated budget request

Thanks to the availability of a basic polarized system inherited from the FZ Julich laboratory, the estimated budget request amounts to 650 kEuro.

4. Participating and partner institutions

INFN Laboratori Nazionali di Frascati - Italy

University of Ferrara – Italy

CERN – Swiss