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Searches for Electric Dipole Moments (EDM) at a Storage Ring with JEDI

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Understanding the origin of the matter-antimatter imbalance in the universe is one of the grand challenges of modern physics. One of the necessary conditions for this matter imbalance is the violation of CP symmetry. Predictions given by the Standard Model fail to explain the observed preponderance of matter by orders of magnitude. Therefore, new sources of CP violation, coming from outside the Standard Model, are needed. They can be seen in Electric Dipole Moments (EDM) of elementary particles.

The efforts of the Jülich Electric Dipole Moment Investigations (JEDI) Collaboration concentrate on the development of the required technologies for a dedicated storage-ring experiment, and a first precursor measurement with deuterons at the Cooler Synchrotron (COSY) using an RF Wien Filter to demonstrate the feasibility of such a study. These proceedings summarize the progress which has been made within the JEDI Collaboration.

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1. Principle of measurement

The principle of an EDM measurement for charged particles like protons or deuterons is based on the observation of the time development of the minuscule vertical-polarization buildup of the beam initially polarized along the particle momentum due to the interaction of a finite EDM with the particle-frame radial electric E field in the storage ring. For an EDM equal to 10^{-29} e·cm the rate of the out-of-the-accelerator-plane precession is of the order of 10^{-9} rad/s, assuming E fields of 10 MV/m.

In general, the particle spin precession in the accelerator plane due to the interaction of the magnetic dipole moment (MDM) with the particle-frame vertical magnetic field is by far larger than the precession caused by the EDM. However, in a dedicated storage ring, a condition of so-called *frozen spin* can be achieved, when the direction of the spin is fixed in the longitudinal direction.

At COSY, which is a purely magnetic ring, spin precesses rapidly in the horizontal plane, with a spin tune of $\nu_s = G\gamma \approx 0.16$ (γ is the Lorentz factor), where the spin tune is the number of spin turns per one accelerator revolution. In such a magnetic ring, if the spin is parallel to the momentum direction, it precesses slightly out of the horizontal plane due to the interaction of the EDM with the radial motional electric E field; when the spin is antiparallel to the momentum, the precession happens in the opposite direction. Therefore, no net vertical polarization build-up can be measured. However, introducing an RF Wien Filter synchronized with the spin precession frequency, a precursory EDM measurement can be performed at COSY, albeit with lower sensitivity than in a dedicated storage ring. The Wien Filter does not introduce any Lorentz force, therefore it has no effect on the orbit and the spin precession due to the EDM. However, its vertical B field can add or subtract an extra precession in the horizontal plane, which can be used to keep the spin longer, e.g., in the forward direction, so the spin precession out the horizontal plane and in the opposite direction will not cancel out. Thanks to this method, a resonant buildup of the vertical polarization can be observed.

2. Achievements of the JEDI collaboration

In order to perform the EDM measurement, a long deuteron polarization lifetime (spin coherence time) in the horizontal plane is required. A spin coherence time of about 1000 seconds has been observed at COSY [1]. It has been achieved through a combination of beam bunching, electron cooling, sextupole field corrections, and suppression of collective effects through beam current limits. In addition, a new method allowing an ultra-high precision of the spin tune measurement has been developed and tested at COSY [2, 3]. An absolute precision of the spin tune measurement of the order of 10^{-8} has been achieved in a time interval of 2.6 s. For a complete 100 s accelerator cycle a precision of the order of 10^{-10} can be achieved.

A precisely determined value of the spin tune serves as an input to the feedback system required to maintain the Wien Filter frequency synchronized with the spin precession, which is crucial for this experiment with the COSY ring. First, the feedback system has been tested with an RF solenoid and used to control the spin precession rate and the phase of the horizontal polarization by changing the frequency of the bunching cavity [4]. With real-time synchronization, the RF solenoid causes the rotation of the polarization out of the horizontal plane, with a rate that depends on the relative phase between the spin and the solenoid field. The rotation rate has showed a sinusoidal dependence on this relative phase, controlled to within a 1-standard-deviation range of σ = 0.21 rad. An analogous experiment has been performed with the Wien Filter during its commissioning. The vertical polarization buildup has been determined as a function of the relative phase between the spin and the Wien Filter set by the feedback system for 3 different rotations of the Wien Filter around the longitudinal axis. Fig. 1 shows the obtained preliminary results. For a rotation of $\pm 1^\circ$, the radial B field component causes spin precession out of the horizontal plane. For a zero degree rotation, corresponding to the ideal vertical direction, the observed buildup can be explained by a stable horizontal B field component, which can originate from ring misalignments. It roughly corresponds to an EDM at the 10^{-18} $e{\cdot}$cm level. These systematic effects for the EDM measurement are currently under investigation.

With the successful commissioning of the Wien Filter, the JEDI collaboration plans to determine an upper limit of the deuteron EDM at COSY after a series of precursory beamtimes in 2019.

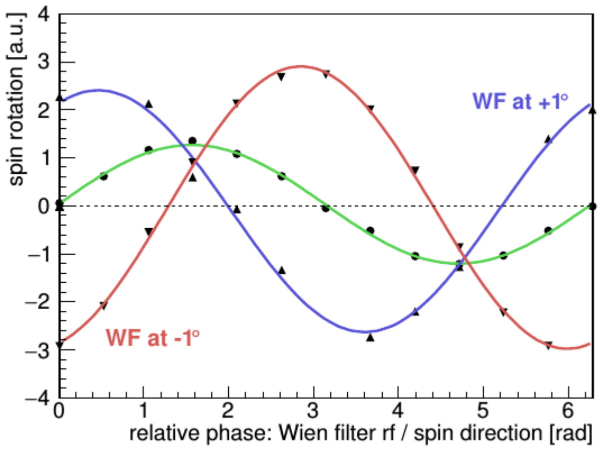

Figure 1: Preliminary vertical polarization buildup rate for three different Wien Filter orientations (vertical orientation and rotations of $\pm 1^\circ$ around the longitudinal axis). Obtained points have been fitted with sinusoidal functions.

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