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Storing muons and freezing spin: development of a fast kicker magnet and electrode system

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Precision storage ring experiments, such as those testing fundamental symmetries and investigating nuclear structure, rely on precise control of electric and magnetic fields to guide, focus and probe charged particles. This is achieved using various techniques, generally involving distributed systems across large scale rings [1-4].
The frozen-spin technique is a yet-undemonstrated approach to search for electric dipole moments (EDMs) of charged particles decaying via the parity-violating weak interaction [5]. A precisely tuned electric field is applied to particles in cyclotron orbits about a magnetic field, cancelling precession induced in the orbital plane by the anomalous magnetic moment, $a = (g-2)/2$. This permits accumulation of spin precession out of the orbital plane, as would be induced by a non-zero EDM. Competitive precision EDM searches are thus rendered feasible using lower momentum in a compact storage ring where fields are localised, presenting both advantages and novel challenges.

The muEDM Collaboration is undertaking such a search with muons [6], for which a small a necessitates an electric field of only $1.8\,\mathrm{kV/cm}$ for $p = 22\,\mathrm{MeV}/c$ muons in a magnetic field of $2.4\,\mathrm{T}$. This will be applied by concentric cylindrical electrodes proximate to the $r = 30\,\mathrm{mm}$ orbit of the muon. Material must be minimised, to reduce multiple Coulomb scattering of emitted positrons, without comprising cylindrical uniformity beyond stringent limits due to systematic effects, especially stray axial electric fields [7].

A pulsed magnetic field will be applied as the muons traverse the centre of the solenoid, reducing their axial momentum and trapping them inside a weakly-focusing magnetic field. The axial confinement permits betatron oscillations up to $\pm 40\,\mathrm{mm}$ due to the wide momentum acceptance of the pulse and absence of an axial cooling scheme. This approach requires a fast kicker magnet to supply current up to 200 A in a $\sim 50\,\mathrm{ns}$ pulse, with subsequent oscillations suppressed below 10 A to avoid systematic effects and maximise spin precession time prior to muon decay.

The motivation and technical development of these localised systems for spin control and trapping on rapid sub-microsecond timescales will be summarised in this poster. In particular, the features of the pulsed power system, developed for characterisation and tests of the kicker magnet, which enable fast-switching will be explained. The electrodes have been designed in parallel to minimise shielding of the pulsed magnetic field and satisfy constraints from systematic effects. These systems will be commissioned in 2025-26, enabling the first attempt to implement the frozen-spin technique, a potential milestone in the field of EDM searches. Moreover, extending the reach of precision trapping and spin control technologies towards shorter timescales offers synergies with precision searches for new physics harnessing polarized short-lived radionuclides increasingly available at modern rare isotope beam facilities [8-10].

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