Test of the Standard Model and Search for Physics Beyond*

Opportunities for Fundamental Physics using Small-scale Storage Ring Experiments

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Abstract

This letter of interest proposes to test the Standard Model (SM) of elementary particle physics and to search for physics beyond (BSM), using storage rings and with a focus on spin-physics. The aim is to investigate BSM using small-scale precision experiments. The involved new technologies are challenging and strongly benefit from a coordinated effort of international laboratories.

Scientific background

Polarized particle beams stored in accelerator rings can be exploited to test fundamental symmetries and the Standard Model of elementary particle physics, as well as to search for physics beyond [1]. A prominent example for such studies is the planned measurement of electric dipole moments (EDMs) of fundamental particles [2, 3, 4]. New aspects which were previously inaccessible, can now be investigated experimentally with the aim of, e.g., testing the SM in new ways [5]. Polarized protons or deuterons stored in a suitable EDM ring may also be directly sensitive to an ambient dark matter (DM) field made of axionlike particles, which could produce oscillating EDMs [6, 7, 8].

Potential of storage rings – the EDM example

It is expected that EDMs of fundamental particles, such as protons, deuterons, helions (^{3}He nuclei) and leptons (electrons and muons), can be measured in storage rings with frozen spin. For protons, a fully-electric machine is considered the ultimate goal. In order to develop the key technologies, a prototype ring needs to be realized beforehand as a test facility [3, Chap. 7]. The suppression of systematic errors makes it essential that the ring lattice supports simultaneously counter-rotating beams. For electrons/positrons and protons, this is possible with fully electric bending. Frozen-spin muons can be obtained by using a radial electric field in a weakly focusing, magnetic storage ring and imply regular reversal of the magnetic field to permit clock-wise and counter-clock wise storage [9]. Simultaneously counter-rotating beams require a large difference between the two beams, either in particle type or in energy [10, 11, 12, 13].

In frozen-spin operation, the bunch polarizations remains globally frozen, e.g., parallel to the beam momentum. With superimposed electric and magnetic bending, the frozen spin condition can be met by fixing the ratio of radial electric to vertical magnetic field, allowing for EDM measurements of many different particle species in one and the same machine [9, 14]. Furthermore, many experiments may be performed with spins that are frozen locally, but not globally, i.e., searches for parity and time-reversal violation with precessing in-plane polarization [5, 15], and tests of co-magnetometry in unequal-beam hybrid storage rings [10, 11, 12]. In that case, a phase-lock is necessary to maintain the local spin orientation [16].

Way forward

Although the needed precision accelerator apparatus represents a remarkable technological challenge, the expertise available in numerous laboratories is adequate to tackle these. Since no individual laboratory, however, is sufficiently qualified to perform all the required tasks, a way forward would be to assemble a consortium of laboratories capable and willing to share the various tasks. Table 1 provides a list of suggested investigations that correlate with the interests of different laboratories. Being far from complete, this table is intended to demonstrate the many physics opportunities available using small-scale storage rings.

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[*] The present "Letter-of-Interest" (LOI), submitted to "RF3: Fundamental Physics in Small Experiments", should be viewed in context with the more dedicated LOI on "Storage Rings for the Search of Charged-Particle Electric Dipole Moments", submitted to "AF5: Accelerators for PBC and Rare Processes".

Table 1: List of opportunities to which laboratories may contribute, in terms of various parameters, bending field, type of particle, beam kinetic energy T, etc. The items are grouped along three themes, small-scale storage rings, physics ideas for new experiments, and new instruments and technical developments.

#	Opportunity	Field	Type	T [MeV]	COSY[a]	BNL	TJNAF	CERN	Cornell	Other	Reference
1	Ultra-high vacuum ring	E	atoms, molecules	0.3			✓			MPIK[b]	[17]
2	EDM prototype	E & B	p	45	✓			✓			[3, Chap. 7]
3	All-electric p-EDM	E	p, p	232.8		✓			✓	FNAL	[18]
4	Frozen-spin muon EDM	B & E	μ^+, μ^-	58						PSI[c]	[4, 19]
5	Time-reversal violation	E & B			✓					JINR[d]	[5]
6	Precision CPT test $G(e^+) - G(e^-)$	B	e^+ & e^-						✓	BINP[e]	[3, App. G.3] [20, 21, 22]
7	Asymmetrically colliding ion beams	E & B			✓			✓		FNAL	[10, 11]
8	Doubly-magic Δ EDM	E & B	$p/^3$He	38.6/39.2	✓	✓					[12], [3, Table G.1]
9	Doubly-magic e^+, p, p-EDM	E & B	e^+/p	30.1/86.6		✓		✓			[12], [3, Table G.1]
10	Deuteron EDM	E & B			✓	✓					[9]
11	Electron EDM	E	e^+/e^-	14.5			✓		✓		[23, 24]
12	Axionlike DM from oscillating EDMs	E	p	45 (#2), 232.8 (#3)	✓						[6, 7, 8]
13	Proton accumulation with cooler	B	p	45	✓	✓		✓			[3, Chap. 7]
14	Polarized ^{3}He source		^{3}He	39.2		✓					[25]
15	Electron polarimetry	B	e^+/e^-	0.5			✓				[26, 27, 28]
16	Polarized e^+ source		e^+	15			✓		✓	SLAC	[29]
17	p, d carbon polarimeter	E & B	p, d	$30 - 300$	✓				✓	FNAL	[f]
18	Pellet extraction sampling	B			✓						[3, App. K]
19	Spin sensitive control	E or B	p				✓				[16]
20	Precision MDM comparator	E & B	various		✓			✓			[3, App. G.3], [22]

[a] COoler SYnchroton COSY [30] operated at Institut für Kernphysik, Forschungszentrum Jülich, Germany
[b] Max-Planck-Institut für Kernphysik, Heidelberg, Germany
[c] Paul Scherrer Institut, Villigen, Switzerland
[d] Joint Institute for Nuclear Research, Dubna, Moscow Region, Russia
[e] Budker Institute of Nuclear Physics, Novosibirsk, Russia
[f] Scattered proton direction and energy by range requires electronics much like the one used in the muon $g - 2$ decay experiment in physics and complexity.

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