

Experimental search for electric dipole moments of light radioactive nuclei

Chavdar Dutsov^{1,*}, Timothy Hume^{1,2}, Maxim Pospelov^{3,4}, and Philipp Schmidt-Wellenburg¹

¹*PSI Center for Neutron and Muon Sciences, 5232 Villigen PSI, Switzerland*

²*ETH Zürich, 8093 Zürich, Switzerland*

³*School of Physics and Astronomy, University of Minnesota, Minneapolis, Minnesota 55455, USA*

⁴*William I. Fine Theoretical Physics Institute, University of Minnesota, Minneapolis, Minnesota 55455, USA*



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We discuss a search for the electric dipole moment (EDM) of a light beta-radioactive ion using a compact ion trap by adapting the “frozen-spin” method. The measurement will be done on ions stripped of their valence electrons, thereby bypassing the significant Schiff screening that hinders the application of successful contemporary EDM searches using heavy neutral atoms and molecules to light nuclei. We identified ^8Li as the most promising candidate for a proof-of-concept EDM search and we estimate that the current indirect proton EDM limit of a few $10^{-25} e \cdot \text{cm}$ set by ^{199}Hg measurements can be surpassed with a week of measurement time at existing facilities.

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I. INTRODUCTION

The search for electric dipole moments (EDMs) represents one of the most promising avenues in particle physics [1] to reveal the nature of beyond Standard Model (SM) physics. A permanent EDM in any fundamental particle or system would constitute direct evidence of time-reversal (T) violation and, through the CPT theorem [2,3], would also violate charge-parity (CP) symmetry. While the Standard Model incorporates CP violation via the complex phase of the Cabibbo-Kobayashi-Maskawa (CKM) matrix [4], its magnitude is insufficient to explain the observed matter-antimatter asymmetry through standard electroweak baryogenesis [5,6]. EDMs thus provide a model-independent probe of new CP -violating physics beyond the SM. Since the pioneering neutron EDM experiment by Purcell, Ramsey, and Smith [7], EDM searches have expanded to diverse systems; neutrons, muons, paramagnetic atoms/molecules (Cs, Tl, YbF, ThO, HfF⁺), and diamagnetic atoms (^{129}Xe , ^{199}Hg , ^{225}Ra , TlF) [1]. Despite decades of measurements, all results remain consistent with zero, placing stringent constraints on CP -violating new physics.

To date, no direct measurement of the proton EDM has been accomplished. The leading experimental proposal involves an all-electric storage ring designed to reach a sensitivity three orders of magnitude beyond that of current neutron EDM searches. This approach requires a storage ring with a circumference of approximately 800m [8–11]. A search for oscillating EDMs induced by axionlike particles, demonstrated using magnetic storage of polarized deuterons at the Cooler Synchrotron COSY (Research Center Jülich, Germany), is an example of initial progress in this direction [12].

So far hadronic CP -violating interactions, particularly the proton EDM, were probed through the nuclear Schiff moment of atoms that have closed electron shells (diamagnetic) [1]. The current best limit on the EDM of such a system is provided by ^{199}Hg ; $7.4 \times 10^{-30} e \cdot \text{cm}$ (95% C.L.) [13].

Despite the exceptional experimental sensitivity, the implications of this result are somewhat reduced due to the large Schiff screening of the nuclear EDM in neutral atoms [14]. Furthermore, extracting fundamental hadronic EDMs from atomic measurements involves an elaborate chain of nuclear and atomic many-body theory, as depicted in Fig. 1.

The ^{199}Hg EDM measurement is interpreted in terms of a Schiff moment, which—under simplified nuclear structure assumptions and theoretical treatment [16]—translates into a constraint on the proton EDM of approximately $2.0 \times 10^{-25} e \cdot \text{cm}$ [13], if it were the sole contributor to the overall EDM.

We propose an alternative search for hadronic CP violation using beta-decaying, fully stripped or closed-shell

*Present address: CERN, Esplanade des Particules 1, Meyrin, Switzerland

†Contact author: chavdar.dutsov@cern.ch

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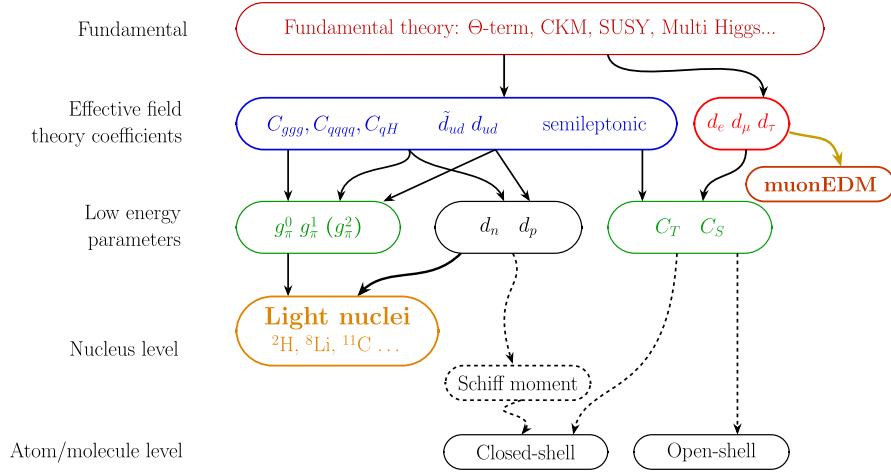


FIG. 1. Illustration of the connection between underlying fundamental theories to laboratory measurements, passing through potential effective CP -violating sources. Note that measurements on fully or partially stripped ions have a more direct and unambiguous connection to low-energy parameters than atoms/molecules. The muonEDM experiment [15], which serves as a blueprint for the light ion search, would measure the EDM of an elementary particle providing a direct connection to fundamental theories. Figure adapted from [1].

light ions confined in a compact ion trap. The partial or complete removal of electrons allows the nucleus to interact directly with an external electric field, substantially mitigating atomic screening and enabling a more direct measurement of the effective nuclear EDM.

As we will demonstrate, sensitivities competitive with or superior to current hadronic EDM limits can be achieved using a compact setup. Unlike the large-scale infrastructure required for storage-ring experiments, the small anomalous magnetic moments (AMM) of selected light ions enable EDM measurements to be performed in a centimeter-scale electromagnetic trap. Our proposed configuration employs an ~ 40 keV ion beam confined in a closed magnetic orbit, producing otherwise more difficult to achieve electric fields of the order of 1–10 MV/m in the ion rest-frame.

The isotope ^8Li in particular serves as an excellent probe due to the very low AMM of the fully stripped state, the high abundance in isotope production facilities, and the fact that it is a standard beta-NMR probe [17]. Moreover, it has unpaired neutron and proton spins, which leads to a balanced sensitivity to both neutron and proton EDMs (d_n, d_p) in contrast to the ^{199}Hg atom, which is predominantly sensitive to the neutron EDM, as shown in Fig. 2. If it can be measured to the same sensitivity, the fully stripped ^9Li is also interesting as a predominantly proton EDM probe.

With an estimated experimental sensitivity of $2.3 \times 10^{-25} e \cdot \text{cm}$, a one-week measurement of ^8Li or ^9Li EDM would significantly improve constraints on d_p , especially in a scenario where neutron and mercury EDM bounds are nearly parallel in the d_n – d_p plane. This makes lithium isotopes particularly attractive for testing new CP violation mechanisms and serves as a stepping stone to

more complex nuclear systems with potentially enhanced CP -violating effects.

The direct search for an EDM of a bare nucleus or a partially stripped ion probes nuclear and hadronic sources of CP violation free of large screening effects. Focusing on ^8Li we will pioneer methods to probe EDMs of light nuclei

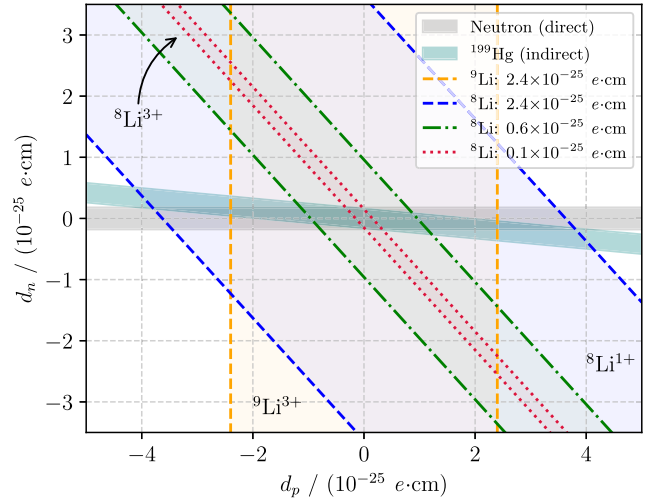


FIG. 2. Constraints in the d_n – d_p parameter space. Light blue and gray are the existing constraints on the mercury and neutron EDMs. The mercury EDM band includes a $\pm 2\sigma$ theoretical uncertainty. The intersection of these two bands sets the limit on the proton EDM, $|d_p| < 4 \times 10^{-25} e \cdot \text{cm}$. Projected sensitivities from ^8Li EDM measurements are shown assuming one week of data collection (blue dashed line), 100 days of data (green dash-dotted line), and 7 days with fully stripped $^8\text{Li}^{3+}$ ions (red dotted line). Even with a one-week measurement, the ^8Li EDM constraint improves existing bounds on d_p .

allowing different sensitivity to specific fundamental sources of CP violation—a necessary addition considering that a global analysis of multiple searches is needed to unambiguously constrain new physics parameters [18].

II. METHODOLOGY

Farley, Semertzidis, Khriplovich, and others [19–21] proposed a method to measure EDMs of charged systems—muons in particular—in storage rings, known as the frozen-spin technique. The essence of the frozen-spin technique is the cancellation of the anomalous ($g - 2$) precession by applying a radial electric field perpendicular to the momentum of the stored particles and to the magnetic field. That way any remaining precession is a consequence of the EDM, which manifests itself through a precession of the spin around the electric-field vector in the particle’s rest frame.

One major advantage of using a storage ring is that the motional electric field experienced by the particle can exceed by far any static field achievable in a laboratory. Furthermore, the frozen-spin technique enables a linear buildup of the EDM signal over time, which is otherwise limited by the much shorter anomalous spin precession period. The frozen-spin muonEDM experiment at the Paul Scherrer Institute (PSI, Switzerland) represents the first attempt to implement this technique, aiming to achieve unprecedented sensitivity in muon EDM measurements [15,22–25].

The electric field strength required to freeze the spin is proportional to the AMM $a = (g - 2)/2$, the beam velocity $\vec{v} = \beta\vec{c}$ and the magnetic field B , while the EDM sensitivity is proportional to $|\vec{v} \times \vec{B}|$. Therefore, the maximum achievable sensitivity is ultimately constrained by the practical limits of the electric field needed to freeze the spin. Systems

with smaller AMM are thus advantageous. For example, the muon, as an elementary particle, has a relatively small AMM of approximately 1.17×10^{-3} .

Although ions do not generally exhibit such small AMM, certain ions possess an effective g -factor near 2, making it possible to apply the frozen-spin technique with more modest electric fields. Khriplovich [19,26] demonstrated this for isotopes with mass number $A > 24$, where ions with AMM similar to the muon can be found, however all highly charged.

Here we extend this approach to lighter nuclei with $A < 24$, particularly ${}^8\text{Li}$, which offers several advantages for a frozen-spin experiment. As a well-established isotope for beta-NMR, ${}^8\text{Li}$ is abundantly produced at isotope production facilities such as TRIUMF (Canada) and ISOLDE (CERN). Furthermore, its relatively simple nuclear structure allows for precise theoretical treatment from first principles.

A. Measurement principle

Figure 3 shows a schematic of the experimental setup of the proposed light ion EDM (LionEDM) spectrometer. We propose to measure the EDM of beta-radioactive ions using a modified version of the compact frozen-spin trap developed for the measurement of the muon EDM at PSI [15]. The apparatus will be located at the exit of the beamline, where spin-polarized ions with kinetic energy $\simeq 42$ keV will travel through a magnetically shielded injection channel into the solenoid.

Achieving high sensitivity requires an intense source of polarized ion beams, such as those available at the VITO beamline at ISOLDE, CERN [17]. At this facility, polarization is transferred from the electron shell to the nucleus via finely tuned laser excitation of the hyperfine structure [27].

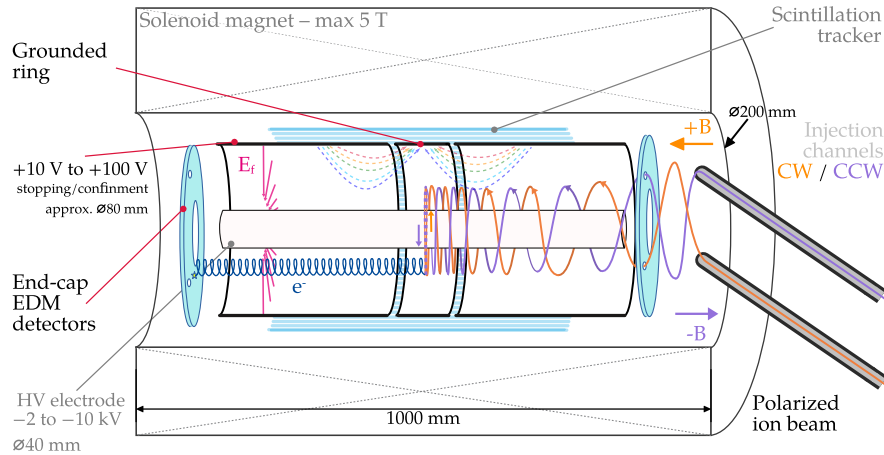


FIG. 3. Schematic cross section of the experimental apparatus (components not to scale). Grayed-out components are already existing in the muonEDM experiment and those indicated in red lines are the new developments needed for storing light ions; an electrode system for stopping and storing ion bunches propagating CW or CCW after injection through magnetically shielded channels, and scintillation beta-decay detectors.

As the ions enter the magnetic field, they will spiral inward with an orbit radius of approximately $R \approx 30$ mm. A timed electric pulse will decelerate them axially, allowing trapping within an electrostatic potential well. The timing of this pulse will be synchronized with the accelerator signal, eliminating the need for an entrance trigger. The pulse, generated by applying an electric field gradient between electrodes separated by 2 mm, on each side of the ground ring in the center, creates an axial electric field. Monte Carlo particle simulations indicate a pulse duration in the range of 1–3 μ s.

Once trapped, the ions will undergo both cyclotron motion and Larmor precession due to the interaction between their spin and the magnetic field. The difference between these two motions is also known as the anomalous or $(g - 2)$ spin precession. To precisely control this effect, a radial electric field is applied within the storage volume. Its strength is carefully tuned to cancel the anomalous spin precession, effectively reducing the total spin-precession frequency to zero in the absence of an EDM.

Like muons, beta-decaying nuclei are “self-analyzing,” meaning their average spin orientation can be measured by tracking the decay products. Parity violation in weak decay leads to a preference for high-energy electrons to be emitted in the direction of the spin. The EDM will be determined from the change in asymmetry, dA/dt , where $A = (N_{\uparrow} - N_{\downarrow})/(N_{\uparrow} + N_{\downarrow})$ represents the difference between the number of electrons emitted parallel or antiparallel to the main magnetic field.

The beta-decay asymmetry A will be measured using end-cap detectors, positioned upstream and downstream along the magnetic field direction, and a scintillation tracker positioned around the ion orbit. The $(g - 2)$ precession frequency will be deduced from the oscillating number of detected decay products in the outer scintillation tracker, similar to the beta-NMR technique.

Once the ion spin is “frozen,” the ion EDM d will be determined from the change of asymmetry in the end-cap detectors,

$$\frac{dA}{dt} = \frac{2}{\hbar} \alpha P d E^*, \quad (1)$$

where $E^* \approx c\beta B + E$ is the electric field strength in the rest frame of the particle, α is the directional asymmetry in the beta-decay, typically ranging from 0.33 to 1 depending on the spin-parity configuration of the initial and final nuclear states, and P is the mean polarization of the ion beam.

B. The frozen-spin technique

The frozen-spin technique is central to the experiment, and we will examine it in more detail here. The relativistic spin motion of a particle moving through electric field $\vec{E}$ and magnetic field $\vec{B}$ is described by the extended Thomas-Bargmann-Michel-Telegdi equation [28–30],

$$\begin{aligned} \vec{\omega} &= \vec{\omega}_a + \vec{\omega}_e \\ &= -\frac{q}{m} \left[a\vec{B} - \left(a + \frac{1}{1 - \gamma^2} \right) \frac{\vec{\beta} \times \vec{E}}{c} \right] \\ &\quad - \frac{\eta q}{2m} \left[\vec{\beta} \times \vec{B} + \frac{\vec{E}}{c} \right], \end{aligned} \quad (2)$$

considering a storage orbit where the particle momentum, magnetic field, and electric field are mutually perpendicular, and adding a term describing the effect of the EDM. Here $\vec{\beta} = \vec{p}c/\mathcal{E}$ and $\gamma = (1 - \beta^2)^{-1/2}$ are the relativistic factors for a particle with total energy $\mathcal{E}$, a is the AMM, and η is the dimensionless constant which relates the spin to the EDM, $\vec{d} = \eta q/(2mc)\vec{s}$.

The anomalous precession frequency $\vec{\omega}_a$ is the difference between the Larmor precession and the cyclotron precession. The second term $\vec{\omega}_e$ arises from the EDM coupling to the electric field in the boosted reference frame of the moving particle. For particles with spin $J > 1/2$, Eq. (2) contains higher order terms with decreasing importance.

By adjusting the electric and magnetic field such that

$$a\vec{B} = \left(a + \frac{1}{1 - \gamma^2} \right) \frac{\vec{\beta} \times \vec{E}}{c}, \quad (3)$$

it is possible to nullify the $(g - 2)$ precession, $\omega_a = 0$. The frozen-spin technique achieves this cancellation of the anomalous precession term by applying an electric field of magnitude $E_f \approx ac\beta\gamma^2|\vec{B}|$. In the absence of an EDM, the spin orientation relative to the particle momentum remains unchanged, “frozen,” during storage.

One approach to fulfill condition (3) and freeze the spin is to use an all-electric storage ring ($B = 0$) and tune the particle momentum such that $\gamma^2 = (a + 1)/a$. This “magic” momentum is then $p = mc/\sqrt{a}$, where m is the particle mass. It results in GeV-scale momentum requiring a storage ring with hundreds of meters circumference for electrostatic storage. This approach is only feasible for particles with relatively large a and relatively low mass, and is considered for searches for the proton and deuteron EDMs [12,31].

In our approach, we opt for a combined electric and magnetic confinement which allows for a very compact storage orbit. However, a large value of a would require excessively strong electric fields, making the frozen-spin technique impractical. Fortunately, for ions, this limitation can be mitigated by adjusting the ion charge z , which fine-tunes the ion’s AMM [19,26]. This flexibility is extremely advantageous, as it enables the use of ions with very small magnetic anomalies, significantly enhancing the sensitivity of the EDM measurement for a given isotope.

C. Sensitivity to the ion EDM

To be sensitive to the nuclear spin, we select ions that are fully stripped or have only paired electrons in their shell. The favorable numbers of electrons are $Z - z = [0, 2, 4, 6, 10, 12, 14, 18, \dots]$ corresponding to an integer number of electron pairs in the electronic shell. Ions with 8 and 16 electrons are omitted as they correspond to p^4 orbitals for which two of the electrons are not paired.

Starting from the equation governing the time evolution of angular momentum in the presence of a magnetic field,

$$\frac{d\vec{J}}{dt} = \vec{\mu} \times \vec{B} = g \frac{q}{2M} \vec{J} \times \vec{B}, \quad (4)$$

where $\vec{J}$ is the angular momentum of an ion with mass M and charge $q = ze$, we express the g -factor of an ion whose electron shell contains only paired electrons as

$$g = \frac{|\vec{\mu}|}{|\vec{J}|} \frac{2M}{q}. \quad (5)$$

Here, the nuclear magnetic moment is given by $\mu = \mu_m \mu_N$, where μ_m is the measured magnetic moment of the nucleus in units of nuclear magnetons, with $\mu_N = \frac{e\hbar}{2m_p}$. Substituting this definition into the expression for g , we obtain

$$g = \frac{\mu_m}{J} \frac{e}{2m_p} \frac{2M}{q} = \frac{\mu_m M}{zm_p J} \approx \frac{\mu_m A}{J z}, \quad (6)$$

where m_p is the proton mass and A is the atomic number of the isotope. An exact formula takes into account the mass excess Δ and the number of missing electrons in the atomic shell zm_e for the ion mass,

$$M = Am_u + \Delta - zm_e, \quad (7)$$

where m_u is the atomic mass constant, $m_u/m_p \approx 0.992776098$ and m_e is the electron mass. Combining Eqs. (6) and (7), the exact g -factor is

$$g = \frac{\mu_m A}{J z} \left(\frac{m_u}{m_p} + \frac{\Delta}{Am_p} - \frac{zm_e}{Am_p} \right). \quad (8)$$

The AMM $a = g/2 - 1$ is then

$$a = \frac{\mu_m}{2m_p J} \frac{Am_u + \Delta - zm_e}{z} - 1. \quad (9)$$

For an ion with atomic number Z and $Z - z$ paired electrons the sensitivity to the EDM is

$$\sigma(d_i) = \frac{\hbar}{2\tau\alpha P E_f} \frac{a}{(a+1)} \frac{Z}{z} \frac{1}{\sqrt{N}}, \quad (10)$$

under the nonrelativistic assumption, valid for the energy scale of the experiment. The factor of Z/z comes from the shielding of the nuclear EDM by the electrons in the shell. The mean free spin precession time due to an EDM is τ which is limited by the lifetime of the isotope or, for longer-lived nuclides, by the spin coherence time.

Taking into account that not all nuclei will decay within the measurement time, the number of detected decay products is

$$N = Y\epsilon(1 - 2^{-\frac{T}{T_{1/2}}}) \frac{D}{\tau}, \quad (11)$$

where Y is the yield in ions per bunch, ϵ is the trapping efficiency, $T_{1/2}$ is the isotope's half-life and D is the total duration of the experiment, such that D/τ represents the number of injected ion bunches. The factor in brackets incurs a penalty for long-lived nuclei where only a fraction of the injected ions would decay during the measurement time.

From Eq. (10) we can see that to maximize the EDM sensitivity, for a given maximum achievable frozen-spin electric field E_f , we require an ion with low AMM a , available in a high ionization state z and in large quantities N .

To identify the optimal ions for EDM searches, we compiled recommended datasets on isotope properties from the evaluated nuclear structure data file (ENSDF) [32] including mass, nuclear spin, and half-life, and supplemented them with nuclear magnetic moment measurements [33,34]. We then filtered for beta-decaying ions that are either fully stripped or have an integer number of electron pairs and calculated their AMM.

Table I contains all ions with $a < 1$, showing their mode of decay and the most probable transition. The reported yield for production at ISOLDE per μC of beam on the target is also given to give a sense of abundance. The typical mode of operation at this facility is 1–2 μC every 1–2.5 s. Note that the yield refers only to $+1$ ions. Additionally, ions with a negative AMM are omitted as for them the frozen-spin electric field acts in the opposite direction of the motional electric field, thus reducing the sensitivity. However, ions with a small negative a or low ionization state are kept as potentially interesting candidates.

Among the candidate isotopes listed in Table I, the fully stripped ^8Li nucleus ($J^\pi = 2^+$, $T_{1/2} = 0.84\text{s}$) emerges as one of the most promising for an EDM measurement. Its favorable characteristics include a small anomalous magnetic moment, a suitable half-life for storage-based experiments, and high production yield. The decay is a pure β^- transition with a 100% branching ratio ($E_{\text{max}} = 13.1\text{ MeV}$) to an excited state of ^8Be , which promptly disintegrates into two $\sim 1.5\text{ MeV}$ alpha particles. These decay products can be easily stopped if necessary

TABLE I. Isotope properties summary ordered by increasing anomalous magnetic moment. The branching ratio refers to the highest probability transition corresponding to the given spin-parity of the final state J^π . All nuclides undergo beta-decay with 100% probability. The mean beta-decay energy $\tilde{E}_\beta$ is also shown. The production yield per μ C proton beam on target is taken from the ISOLDE database [35,36].

Ion	μ, μ_N	a	$J^\pi \rightarrow J^{\pi'}$	Branching (%)	$T_{1/2}, s$	$\tilde{E}_\beta, \text{keV}$	Yield, μC^{-1}
$^{13}\text{O}^{6+}$	1.389	-0.002	β^+ $3/2^- \rightarrow 1/2^-$	89.2	0.009	8136	...
$^{18}\text{N}^{3+}$	0.327	-0.024	β^- $1^- \rightarrow 1^-$	47.2	0.619	4485	6.5×10^1
$^{19}\text{O}^{6+}$	1.532	-0.036	β^- $5/2^+ \rightarrow 3/2^+$	54.4	26.880	1442	1.3×10^5
$^9\text{C}^{4+}$	1.391	0.039	β^+ $3/2^- \rightarrow 3/2^-$	54.1	0.127	7502	4.0×10^3
$^{22}\text{F}^{7+}$	2.694	0.051	β^- $4^+ \rightarrow 4^+$	53.9	4.230	2449	2.5×10^4
$^{17}\text{C}^{4+}$	0.758	0.067	β^- $3/2^+ \rightarrow 1/2^+$	27.0	0.191	5413	8.0×10^0
$^{12}\text{N}^{3+}$	0.457	-0.091	β^+ $1^+ \rightarrow 0^-$	96.2	0.011	7923	...
$^8\text{Li}^{3+}$	1.653	0.097	β^- $2^+ \rightarrow 2^+$	100.0	0.840	6248	5.8×10^8
$^{16}\text{N}^{7+}$	1.986	0.127	β^- $2^- \rightarrow 6/2^-$	66.2	7.130	1942	2.5×10^4
$^{17}\text{N}^{7+}$	0.355	-0.143	β^- $1/2^- \rightarrow 3/2^-$	50.3	4.171	1457	1.0×10^5
$^{20}\text{F}^{9+}$	2.093	0.154	β^- $2^+ \rightarrow 2^+$	100.0	11.070	2482	9.7×10^6
$^{12}\text{B}^{5+}$	1.003	0.196	β^- $1^+ \rightarrow 0^-$	98.2	0.020	6439	...
$^{17}\text{N}^{5+}$	0.355	0.199	β^- $1/2^- \rightarrow 3/2^-$	50.3	4.171	1457	1.0×10^5
$^{17}\text{Ne}^{10+}$	0.787	0.330	β^+ $1/2^- \rightarrow 3/2^-$	49.0	0.109	3806	4.5×10^3
$^{15}\text{O}^{8+}$	0.719	0.338	β^+ $1/2^- \rightarrow 1/2^-$	99.9	122.240	735	...
$^{14}\text{B}^{3+}$	1.185	0.375	β^- $2^- \rightarrow 1^-$	79.0	0.012	7024	...
$^{13}\text{N}^{3+}$	0.322	0.385	β^+ $1/2^- \rightarrow 1/2^-$	99.8	597.900	492	2.4×10^4
$^{19}\text{O}^{4+}$	1.532	0.445	β^- $5/2^+ \rightarrow 3/2^+$	54.4	26.880	1442	1.3×10^5
$^{22}\text{F}^{5+}$	2.694	0.471	β^- $4^+ \rightarrow 4^+$	53.9	4.230	2449	2.5×10^4
$^{20}\text{F}^{7+}$	2.093	0.484	β^- $2^+ \rightarrow 2^+$	100.0	11.070	2482	9.7×10^6
$^{13}\text{O}^{4+}$	1.389	0.497	β^+ $3/2^- \rightarrow 1/2^-$	89.2	0.009	8136	...
$^{21}\text{Na}^{11+}$	2.386	0.507	β^+ $3/2^+ \rightarrow 3/2^+$	94.8	22.490	1110	4.0×10^8
$^{16}\text{N}^{5+}$	1.986	0.577	β^- $2^- \rightarrow 6/2^-$	66.2	7.130	1942	2.5×10^4
$^{25}\text{Na}^{11+}$	3.683	0.661	β^- $5/2^+ \rightarrow 5/2^+$	62.5	59.100	1714	2.6×10^9
$^{17}\text{Ne}^{8+}$	0.787	0.662	β^+ $1/2^- \rightarrow 3/2^-$	49.0	0.109	3806	4.5×10^3
$^{17}\text{F}^{9+}$	4.721	0.770	β^+ $5/2^+ \rightarrow 5/2^+$	99.9	64.490	739	1.1×10^7
$^{15}\text{O}^{6+}$	0.719	0.785	β^+ $1/2^- \rightarrow 1/2^-$	99.9	122.240	735	...
$^{21}\text{F}^{9+}$	3.919	0.815	β^- $5/2^+ \rightarrow 5/2^+$	74.1	4.158	2452	9.4×10^5
$^{20}\text{Na}^+$	0.369	0.834	β^+ $2^+ \rightarrow 2^+$	79.3	0.448	5392	1.1×10^6
$^{21}\text{Na}^{9+}$	2.386	0.842	β^+ $3/2^+ \rightarrow 3/2^+$	94.8	22.490	1110	4.0×10^8
$^{12}\text{B}^{3+}$	1.003	0.994	β^- $1^+ \rightarrow 0^-$	98.2	0.020	6439	...
$^{17}\text{N}^{3+}$	0.355	0.999	β^- $1/2^- \rightarrow 3/2^-$	50.3	4.171	1457	1.0×10^5
$^8\text{B}^+$	1.036	1.062	β^+ $2^+ \rightarrow 2^+$	88.0	0.770	6732	6.4×10^4
$^9\text{C}^{2+}$	1.391	1.079	β^+ $3/2^- \rightarrow 3/2^-$	54.1	0.127	7502	4.0×10^3
$^8\text{Li}^+$	1.653	2.292	β^- $2^+ \rightarrow 2^+$	100.0	0.840	6248	5.8×10^8
$^9\text{Li}^{3+}$	3.437	2.421	β^- $3/2^- \rightarrow 3/2^-$	49.2	0.178	6562	3.6×10^7

and may serve as useful beam diagnostics during storage. The beta-decay asymmetry parameter for ^8Li is $\alpha = 1/3$.

D. Experimental sensitivity

The most favorable lithium ion, $^8\text{Li}^{3+}$, is experimentally challenging to obtain because a polarized beam of fully stripped nuclei is currently not available. However, the single charged state is a common beta-NMR probe with reported polarization levels up to 69% [37]. Although it has a relatively large anomalous magnetic moment ($a = 2.29$),

$^8\text{Li}^+$ can serve as a precursor to validate key techniques with single charged ions, albeit with reduced sensitivity.

Using the frozen-spin trap developed for the muon EDM search [15] we will demonstrate the feasibility using single charged ions. The nominal orbit radius in the experiment is fixed to 30 mm and the maximum achievable electric field is of the order of 2 MV/m [38]. The solenoid can produce fields of up to 5T, however, longitudinal beam injection requires shielding of the fringe fields. Magnetic fields up to about 1T can be shielded with steel or iron, while stronger fields necessitate superconducting channels. To simplify a

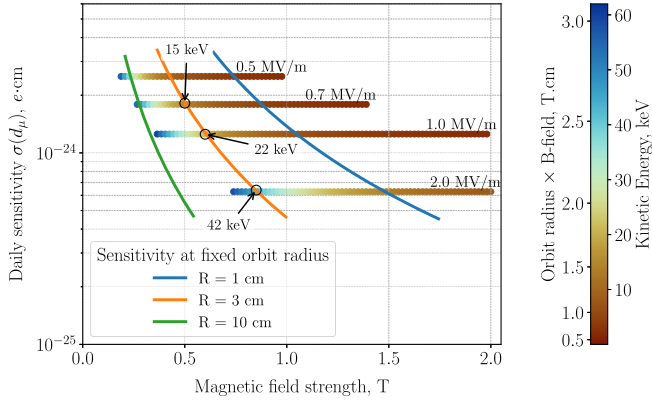


FIG. 4. Daily sensitivity to the EDM of singly charged ^8Li ions as a function of the strength of the confining magnetic field. The color gradient shows the kinetic energy of the particles for a given frozen-spin electric field. The three solid lines show the sensitivity at a fixed value of the orbit radius. A storage time of 1 s is assumed.

proof-of-concept experiment, operation at lower fields is preferable.

Figure 4 shows the estimated daily sensitivity to the EDM of $^8\text{Li}^+$ as a function of the key parameters; applied electric and magnetic fields, beam kinetic energy, and orbit radius inside the ion trap. In the nonrelativistic approximation, applicable for the discussed energy scale where $(\gamma - 1) < 5 \times 10^{-6}$, the relationship between the magnitude of the frozen-spin field, the orbit radius, and the magnetic field is

$$|E_f| = \frac{q}{m} a(a+1) B^2 R. \quad (12)$$

The required kinetic energy for this condition is

$$K = \frac{(q(a+1)BR)^2}{2m}. \quad (13)$$

Note that, from Eq. (9), it follows that $q(a+1)$ is approximately constant for a given isotope. Consequently, the required electric field scales linearly with the magnetic anomaly a , while remaining independent of the ion's charge state. As a result, the kinetic energy also remains unaffected by the charge state.

Equations (10) and (11) were used to estimate the daily sensitivity in Fig. 4. The trapping efficiency, $\epsilon = 1\%$, is estimated by scaling the muonEDM efficiency due to the much lower emittance of the ion beamline (6 mm mrad)¹ compared to the muon beamline (200 mm mrad). Given the significantly smaller phase space and energy spread of the ion beam compared to the muonEDM experiment at PSI, a

higher injection efficiency is expected, corresponding to 5.6×10^6 particles per fill every 5 s.

The three points in Fig. 4 show possible configurations of the LionEDM experiment at 3 cm orbit radius, all possible to implement in the muonEDM apparatus. The $K = 42$ keV point corresponds to $6.4 \times 10^{-25} e \cdot \text{cm}$ daily or $2.4 \times 10^{-25} e \cdot \text{cm}$ weekly sensitivity. The latter corresponds to 20 $\mu\text{rad/s}$ spin precession.

The velocity of the beam in this configuration is $\beta c \approx 3.4 \times 10^{-3} c$ or 1000 mm/ μs . After exiting the injection channel, the beam will spiral towards the storage area with a longitudinal velocity 10 mm/ μs , corresponding to 10 mrad pitch of the helix.

The particle beam can then be decelerated and stopped in the center by an electric field gradient of about 10 V/m generated by a Penning-traplike configuration, shown in Fig. 3. Once confined, the beam would orbit in the 2 MV/m radial electric field generated by concentric cylindrical electrodes. The high-voltage required to generate this field strength is 20 kV, keeping a spacing of 10 mm between the electrodes.

The trajectory of the decay products coming from the stored nuclei will be deduced from scintillating trackers placed around the outer electrode. The mean beta-decay energy of 6.2 MeV for ^8Li results in electron tracks within a 0.5-T-field that are similar in spatial distribution as the positrons tracks from muon decay, for which the muonEDM experiment was optimized. The latter is conducted at a higher magnetic field of 2.5 T and detects positrons in the range of 25–66 MeV. The need for a tracker outside the outer electrode places stringent constraints on its thickness and material composition as the decay particles need to escape and, ideally, make a few turns before stopping in the material.

Electrons emitted in the lower energy region of the beta-decay spectrum, as well as electrons with a low transverse momentum, will be detected by end-cap detectors placed up- and downstream of the electrode system. These end-cap detectors are sufficient to collect all decay particles for the case that $^8\text{Li}^{3+}$ becomes available as then one would run the experiment at a much higher magnetic field where the electron tracks are confined in the volume between the electrodes.

Storing the low-energy ion beam for a long period of time requires ultrahigh vacuum. At the level of 10^{-8} mbar, the ions would lose close to 1% of their kinetic energy in 1 s of storage time. Reaching this level of vacuum requires differential pumping to separate the experiment from the beamline, which is typically at 10^{-6} mbar.

To freeze the spin-motion due to the anomalous magnetic moment, the electric field must be precisely tuned. Nevertheless, a spread in the kinetic energy of the particles in the bunch leads to a gradual loss of polarization and reduction of sensitivity. The anomalous spin precession frequency,

¹ISOLDE Newsletter 2023, CERN, <https://isolde.cern/>, accessed on 3 June 2025.

$$\omega_a = -\frac{q}{m} \left(aB - \frac{E}{\beta c} \right), \quad (14)$$

depends on the electric and magnetic field experienced by the individual particle. While the solenoidal magnetic field is constant throughout the storage volume, the radial electric field strength generated by the concentric electrodes decreases with $1/R$ following Gauss's law. Therefore, particles with higher than nominal velocity experience a lower electric field, contrary to the required higher electric field that would be needed to satisfy (3). This will lead to a gradual dephasing of the spin orientation as a function of the energy spread. Taking the derivative of (14) with respect to the kinetic energy, we obtain the spread of ω_a ,

$$\sigma(\omega_a) = a \frac{qB}{m} \delta(K), \quad (15)$$

as a function of the relative spread in K , where $\delta(K) = \sigma(K)/K$. The spin-coherence time is then approximately $T_s = 2\pi/\sigma(\omega_a)$.

For ion beams originating from surface ionization or laser ablation sources, the relative energy spread is typically $\delta(K) \cong 1 \times 10^{-4}$, i.e., several eV. This corresponds to a spin coherence time of only $T_s = 2.7$ ms for ${}^8\text{Li}^+$ ions stored at 42 keV kinetic energy in a 0.85T magnetic field. Such a coherence time is far shorter than the possible ion storage time. Moreover, a finite beam divergence contributes an additional spread in orbital kinetic energy. A transverse divergence θ changes the orbital velocity fractionally by $\theta^2/2$, and hence the orbital kinetic energy by θ^2 . To achieve a 1 s spin coherence time, one requires $\theta^2 \leq 3 \times 10^{-7}$, i.e., $\theta \leq 0.5$ mrad.

From these constraints we can infer the necessary input beam quality in terms of emittance. The longitudinal emittance $\xi_{\text{long}} \approx \pi \Delta E \Delta t$ is given by the product of the bunch temporal width with its energy spread. For a successful measurement one requires $\xi_{\text{long}} \cong 0.013$ eV μ s, corresponding to $\Delta E = 12$ meV and $\Delta t = 1$ μ s. The transverse emittance should be limited to $\xi_{\text{trans}} < 0.5$ mm mrad in order to suppress beam divergence, extend spin coherence, and maintain a spot size below 1 mm for efficient injection into the trap channels.

Direct injection from the ion source is therefore not feasible due to its intrinsically large emittance. Prior to delivery to the frozen-spin ion trap, the beam must be cooled and bunched. For that purpose, room-temperature radio-frequency quadrupole cooler-bunchers (RFQcb) are commonly used in radioactive ion beam facilities, using buffer-gas cooling. One such RFQcb is already operational at the high-resolution spectrometer beamline at CERN-ISOLDE [39], however, its extraction emittance is too large for a light-ion EDM experiment. A cryogenic implementation, by contrast, can provide the required phase space compression. Recently, Lechner *et al.* demonstrated in

simulations $\xi_{\text{long}} = 0.02$ eV μ s and $\xi_{\text{trans}} = 0.02\pi$ mm mrad for ${}^{20}\text{Mg}^+$ ions using a cryogenic Paul trap with He buffer gas at 40K, which is being developed in the context of the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) also at CERN-ISOLDE [40]. For ${}^8\text{Li}^+$, an even smaller transverse emittance can be expected, scaling approximately with the square root of the mass ratio between lithium and magnesium.

Another possibility that will be explored to achieve long term spin coherence is to apply dedicated techniques like those used at COSY where a 1000 s proton beam polarization lifetime was reported [41], or spin-echo pulse schemes to cancel relative dephasing similar as in Ref. [42].

Overall, the ${}^8\text{Li}^+$ ion is an ideal candidate for this pioneering study due to its well-established high-polarization technique and simple nuclear structure, which facilitates interpretation of results. Even at low magnetic fields, a single day of measurement could achieve 10^{-24} e $\cdot$ cm sensitivity, which approaches the best indirect proton EDM limits. The important parameters of the experiment are summarized in Table II.

Significant improvements in EDM sensitivity can be achieved using fully stripped nuclei. The ${}^8\text{Li}^{3+}$ state offers an eightfold enhancement due to its 24 times lower AMM compared to ${}^8\text{Li}^+$, following the $a/(a+1)$ scaling in Eq. (10). A further threefold improvement arises from reduced electron shielding, described by the Z/z factor in Eq. (10). If the experiment is limited by the spin-coherence time, sensitivity improves linearly with aq , yielding an additional eightfold enhancement.

When transitioning from single charged to fully stripped ions statistical losses might occur due to the electron stripping process. Nonetheless, the resulting sensitivity improvement ranges from two to three orders of magnitude, making fully stripped ${}^8\text{Li}$ a highly promising probe for future EDM searches. Moreover, the systematic effects arising from the coupling of the AMM to the experiment's

TABLE II. Key parameters for a ${}^8\text{Li}^+$ proof-of-concept EDM experiment.

Anomalous magnetic moment a	2.29
Mean β -decay energy	6.2 MeV
Nominal orbit radius R	30 mm
Kinetic energy K	42 keV
Beam velocity βc	$3.4 \times 10^{-3} c$ (1000 mm/ μ s)
Frozen-spin electric field E_f	2 MV/m
Confining solenoidal B -field	850 mT
Input beam emittance	$\xi_{\text{long}} \leq 0.01$ eV $\cdot\mu$ s; $\xi_{\text{trans}} \leq 0.5$ mm mrad
Particles per fill	5.6×10^6 every 5 s
Storage time	1 s
Vacuum requirement	$< 10^{-8}$ mbar
Weekly EDM sensitivity	2.4×10^{-25} e $\cdot$ cm
Corresponding spin precession	20 μ rad/s

electromagnetic fields would be reduced by a factor of 24, further enhancing sensitivity limits.

E. Systematic effects and countermeasures

Reaching high sensitivity to light ion EDMs requires a stringent control of spurious effects that mimic a true EDM signal. The dominant systematic effects in a frozen-spin trap were originally laid out in [21] and later elaborated specifically for the muonEDM experiment in [43]. The most critical systematic effect is the presence of a net radial magnetic field component, $\langle B_r^* \rangle \neq 0$, in the rest frame of the particle. It can be generated by an axial E-field component E_z or a radial B-field component, B_r , in the laboratory frame. Both field components exert Lorentz force on the ions, and so, the mean axial force in the laboratory frame

$$q\langle E_z + c\beta B_r \rangle = 0, \quad (16)$$

for the orbit to be stable axially.

In a purely magnetic or purely electric confinement $\langle B_r^* \rangle = 0$ for trapped particles, as otherwise there will be a net force which accelerates them out of the storage region, and so there would be no systematic effect [21]. However, one cannot completely eliminate stray fields and in the general case the ions will be trapped in a combination of electric and magnetic fields. Here we will examine the motion of ions in the frozen-spin trap to estimate the necessary level of control of the electromagnetic fields in the experiment to achieve the target sensitivity.

The radial magnetic field around the center of the solenoid can be approximated to first order by a magnetic field gradient $B_r(z, t) = z(t)\partial_z B_r$, where $\partial_z \equiv \partial/\partial z$. Similarly, the electrostatic axial trapping potential can be approximated by $E_z(z, t) = (z(t) - \Delta_z)\partial_z E_z$, where Δ_z is the separation between the zero crossings of the E-field and B-field gradients, and accounts for the possibility that the confining electrodes are not ideally symmetrically placed around the center of the solenoid.

The axial motion of an ion is then

$$m\ddot{z}(t) = q(\partial_z E_z(z(t) - \Delta_z) + c\beta\partial_z B_r z(t)), \quad (17)$$

where $c\beta = \sqrt{2K/m}$ is the velocity of the particle along its orbit. The solution of Eq. (17), assuming $z(0) = z_0$, is

$$z(t) = \frac{q}{m} \frac{\partial_z E_z(z_0 - \Delta_z) + c\beta\partial_z B_r z_0}{\varpi^2} \cos(\varpi t) + \frac{q}{m} \frac{\partial_z E_z \Delta_z}{\varpi^2}, \quad (18)$$

a harmonic oscillator with angular frequency $\varpi = \sqrt{-q/m(\partial_z E_z + c\beta\partial_z B_r)}$. Note that negative field gradients yield a real frequency, and therefore confinement. The constant term

$$z_{\text{eq}} = \frac{q}{m} \frac{\partial_z E_z \Delta_z}{\varpi^2} \quad (19)$$

is the z -position of the equilibrium of this harmonic oscillator.

In the absence of the constant term in Eq. (18), the particle will oscillate around zero, and thus, if there is no spatial separation Δ_z between the axially confining E-field and the center of the solenoid, no systematic effect will be generated. If the fields are not overlapping ideally, a net spin rotation

$$\omega_f = \frac{q}{m} \left(a\partial_z B_r z_{\text{eq}} - \frac{\partial_z E_z (z_{\text{eq}} - \Delta_z)}{c\beta} \right) \quad (20)$$

will be observed.

Substituting (19) into (20), the resulting EDM-like precession frequency can be expressed as

$$\omega_f \simeq \frac{q}{m} a\partial_z B_r \Delta_z, \quad (21)$$

as a function of the separation Δ_z between the electric and magnetic field zero crossings, assuming $c\beta\partial_z B_r \ll \partial_z E_z$. The latter is already required to suppress systematic effects by ensuring sufficiently small magnetic-field gradients.

A magnetic-field uniformity with gradients below 30nT/mm was demonstrated in Fermilab's muon $g - 2$ storage ring experiment [44,45]. Achieving a similar level of shimming for the main solenoid and constraining $\Delta_z \leq 0.1 \mu\text{m}$, the false spin precession of $^8\text{Li}^+$, would be limited to less than the required 20 $\mu\text{rad/s}$. However, direct measurement of Δ_z to that precision is experimentally challenging. To control this systematic contribution ω_f and isolate the true EDM signal, we follow a strategy analogous to the crossing-point analysis used in the nEDM experiment that placed the most stringent upper limit on the neutron EDM with a sensitivity of $1.8 \times 10^{-26} e \cdot \text{cm}$ (90% C.L.) [46].

In the presence of a permanent EDM, the measured precession frequency takes the form

$$\omega_m = \omega_f + \omega_e = \frac{q}{m} a\partial_z B_r \Delta_z + \omega_e, \quad (22)$$

which is a linear relation of the form $y = kx + b$ with $x \equiv \Delta_z$. Measuring ω_m as a function of Δ_z therefore yields a straight line with slope directly related to the axial gradient of the radial magnetic field $\partial_z B_r$. The separation Δ_z can be varied by adjusting the voltages on the axial confinement electrodes surrounding the grounded ring (see Fig. 3).

The CP —and T -violating character of the EDM enables a time-reversal-symmetric measurement. This is implemented by reversing the currents in all coils, thereby inverting the magnetic-field direction, and by switching

the beam propagation from clockwise (CW) to (counter-clockwise) CCW. A second measurement is then performed under the inverted magnetic-field gradient, again scanning over Δ_z . This yields another straight line with a modified slope but the same intercept, ω_e . The two lines intersect at $\Delta_z = 0$, where the systematic effect cancels, leaving the observed spin-precession frequency equal to the EDM-induced value ω_e .

Another potential systematic effect in the experiment could arise from oscillations of the electromagnetic field in the ion's rest frame. Small fluctuations around the nominal field along perpendicular axes would induce spin rotations; since such rotations do not commute, their interplay can generate a net rotation that mimics an EDM signal. For instance, ions traveling slightly off the nominal orbit experience an oscillating electric field around the frozen-spin value. This can couple to an oscillating magnetic-field component along the ion trajectory, leading to a gradual phase accumulation. This effect is an example of Berry's phase [47].

Systematic effects of this type were studied in detail for the muonEDM experiment [43]. While they were found negligible in that context, they may become relevant for light-ion experiments due to higher sensitivity and longer observation times. Nonetheless, several mitigating factors exist. Phase accumulation is significant only for resonant oscillations along two perpendicular axes, which greatly restricts possible error sources. Moreover, the effect cancels to first order when using the CW/CCW injection scheme. Finally, the spin's oscillation frequencies and amplitudes around different axes can be reconstructed from the measured decay products of the ions. This information enables calculation and correction of the EDM-like phase shift.

F. Sensitivity to fundamental CP -odd parameters

Results from EDM searches using light ions in a compact storage trap can be related to the fundamental CP -odd parameters. In this subsection, we address the physics potential of measuring the EDMs of ${}^8\text{Li}$ and ${}^9\text{Li}$ ions employing an intermediate model of CP violation parametrized in terms of the nucleon EDMs, $\{d_p, d_n\}$. While the neutron EDM limits are well-known [46], the indirect limits on the proton EDM can be extracted from atomic EDM measurements [16,48]. Here we use the results of Ref. [16] that relate the experimental results on the EDM of ${}^{199}\text{Hg}$ atom [49] with d_p and d_n ,

$$\left| d_n + \frac{0.2 \pm 0.02}{1.9} d_p \right| < 1.6 \times 10^{-26} \text{ e cm},$$

$$|d_n| < 1.8 \times 10^{-26} \text{ e cm}. \quad (23)$$

Due to the absence of the valence protons on the outer shell of ${}^{199}\text{Hg}$, the sensitivity to d_p is markedly reduced. The combination of the neutron and mercury EDM

experiments significantly constrains d_n but produces a limit on d_p that is considerably weaker.² On a two-dimensional $\{d_p, d_n\}$ plane, neutron and mercury EDM constraints can be represented by the two almost parallel bands, see Fig. 2.

In contrast to ${}^{199}\text{Hg}$, the nucleus of ${}^8\text{Li}$ ion contains five neutrons and three protons, and both d_n and d_p will contribute to the nuclear EDM. Employing a naive shell model, ${}^8\text{Li}$ is treated as a ${}^4\text{He}$ core plus four valence nucleons—three neutrons and one proton—occupying p -wave orbitals. The single particle configuration should be $(p_{3/2})_n^3(p_{3/2})_p^1$. If all four nucleons were neutrons in the $(p_{3/2})$ shell, antisymmetrization would require them to fill all m_j sublevels, resulting in a $J = 0$ state. Thus, the $(p_{3/2})_n^3$ configuration corresponds effectively to a single neutron hole in the $p_{3/2}$ shell, giving total angular momentum $J = 3/2$. For the EDM problem, this neutron hole can be thought of as an actual neutron in the $p_{3/2}$ state, and its magnetic moment and EDM will be same as for a real neutron. The same conclusion could be made for the proton, effectively giving a $(p_{3/2})_n^1(p_{3/2})_p^1$ state.

Hence, to a good approximation, the unpaired nucleons in ${}^8\text{Li}$ are one neutron and one proton, both in $p_{3/2}$ states. When combining two angular momenta $j = 3/2$, the total angular momentum can range from $J = 0$ to $J = 3$. The observed $J^\pi = 2^+$ ground state arises from more complex configuration mixing, but for an EDM estimate, we can construct the $|J = 2, M = 2\rangle$ state directly from coupled $|3/2, m\rangle_n |3/2, m'\rangle_p$ states. This approach is limited and in a more realistic model, there would be admixtures of other states like $p_{1/2}$. Nevertheless, we can evaluate the magnetic moment of ${}^8\text{Li}$ in this simplified model to estimate its validity.

Using vacuum values for the spin and orbital g -factors of the proton and neutron, this simple model yields a magnetic moment of $\mu \approx 1.25\mu_N$ for ${}^8\text{Li}$, which compares favorably to the shell-model prediction of 1.366 by Cohen and Kurath as cited in Ref. [50] and the experimental value of $1.65\mu_N$. While this $\approx 25\%$ deviation reflects the crudeness of the model, it is sufficient to evaluate the sensitivity to the neutron and proton EDMs in a lithium experiment.

Within the same simplistic model we can calculate the EDM of ${}^8\text{Li}$. To do that we assume that the ground state of lithium nucleus is fully polarized, and is in the $|J = 2, M = 2\rangle$ state. This gives

$$d_{8\text{Li}} = \langle 2, 2 | d_p \sigma_{pz} + d_n \sigma_{nz} | 2, 2 \rangle = \frac{2}{3} (d_n + d_p), \quad (24)$$

where σ_{pz} and σ_{nz} are the spin operators of the valence proton and neutron projected along the quantization axis.

²Moreover, the presence of T , P -odd nuclear forces could lead to a further relaxation of a strict limit on d_p .

Relation (24) demonstrates that ${}^8\text{Li}$ has significant sensitivity to both d_n and d_p . For comparison, the sensitivity to d_p is substantially higher than that of ${}^{199}\text{Hg}$. As illustrated in Fig. 2, an experimental sensitivity at the level of $\mathcal{O}(10^{-25})e\cdot\text{cm}$ would surpass existing constraints on the proton EDM.

Moreover, these results can be made considerably more precise using the *ab-initio* techniques of the nuclear theory applicable to low A nuclei. Such methods have already been successfully applied to calculate the EDMs of ${}^6\text{Li}$, ${}^9\text{Be}$, and ${}^{13}\text{C}$ [51], as well as ${}^7\text{Li}$ and ${}^{11}\text{B}$ [52]. In the future, one can also include the influence of the CP -odd nuclear forces on EDMs of lithium isotopes, and it is expected to be a more feasible task than a corresponding calculation for the mercury EDM, where it remains to be rather difficult [53].

Light nuclei can also be treated from first principles using effective field theory, similar to the deuteron [54]. As shown in Ref. [55], EDM measurements of the deuteron and helion in storage rings can discriminate between flavor-diagonal sources of CP violation, including the QCD θ -term, the minimal left-right symmetric model, and related scenarios. Furthermore, P - and T -violating nuclear forces can be systematically derived within chiral effective field theory, which provides a link between quark-level interactions and nuclear observables [56]. These approaches could also be extended to ${}^8\text{Li}$, offering enhanced sensitivity to physics beyond the SM.

III. CONCLUSIONS

The measurement of EDMs in light ions confined in compact traps represents an exciting opportunity in the ongoing search for new sources of CP violation. Current state-of-the-art EDM experiments predominantly target heavy neutral atoms such as ${}^{199}\text{Hg}$, ${}^{225}\text{Ra}$, or molecular systems like ${}^{205}\text{TlF}$, or rely on large-scale infrastructure such as storage rings operating at the magic momentum for protons and deuterons. These approaches, while powerful, are inherently limited by theoretical complexity or scale.

In contrast, light ion systems offer a complementary and potentially more accessible path. Among these, we show that the fully stripped ${}^8\text{Li}$ ion is a uniquely promising

candidate. Its low anomalous magnetic moment, favorable nuclear structure, and accessibility to first-principles theory make it particularly well-suited for EDM searches in a frozen-spin trap. We estimate a sensitivity of $1 \times 10^{-26} e\cdot\text{cm}$ within a single week of data collection, assuming an ion yield of 5.6×10^6 ions every 5 s.

While the production of fully stripped, polarized ${}^8\text{Li}$ beams remains a technical challenge, the singly charged ${}^8\text{Li}$ ion—widely used in β -NMR applications—offers a practical and immediate path toward a proof-of-principle experiment. Remarkably, such a precursor study could surpass current proton EDM limits derived from ${}^{199}\text{Hg}$ with only a few days of measurement time.

Beyond the immediate prospects of ${}^8\text{Li}$, the successful implementation of a frozen-spin ion trap would enable precision measurements across a broad range of light ions, each probing distinct facets of CP symmetry violation, and would give access to a new path toward uncovering physics beyond the Standard Model.

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DATA AVAILABILITY

The data that support the findings of this article are openly available [32,35,57].

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