Deuteron EDM Systematic Error Study Plan

by the Storage Ring EDM Collaboration

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Introduction

The relative sensitivity of the deuteron EDM (dEDM) experiment compared to other hadronic EDM efforts can be summarized with the slide, shown as Table 1, presented to the fall 2006 PAC meeting at BNL by Bill Marciano.

Comparison With Other EDM Efforts

	Current Bound	Future Goal	$\sim d_n$ Equivalent
Neutron	$d_n < 3\times10^{-26}$ e-cm	$\sim 10^{-28}$ e-cm	10^{-28} e-cm
^{199}Hg atom	$d_{Hg} < 2\times10^{-28}$ e-cm	$\sim 2\times10^{-29}$ e-cm	10^{-25} - 10^{-26} e-cm
^{129}Xe atom	$d_{Xe} < 6\times10^{-27}$ e-cm	$\sim 10^{-30}$ - 10^{-33} e-cm	$10^{-26} \sim 10^{-29}$ e-cm
Deuteron	-	10^{-29} e-cm	3×10^{-29} - 5×10^{-31} e-cm

Table 1. The deuteron EDM at 10^{-29} e·cm could provide a superior of sensitivity in the search for hadronic EDMs.

Clearly, the strength of the dEDM experiment is that it could provide the farthest reach in sensitivity in the hadronic EDM field. Expressed in terms of an equivalent mass scale, this physics reach is 10^3 TeV for a CP-violating phase of order 1 or, if SUSY exists at the LHC energy scale, is 10^{-5} rad for a CP-violating phase. Both sensitivity levels are well beyond the designed sensitivity of the LHC.

This sensitivity is made possible by implementing a new technique as described in the LOI submitted in 2006 [1]. This new technique, however, poses new challenges as well, as was also recognized by the PAC in its report. The PAC recommended that the collaboration should identify the most important systematic errors and develop a comprehensive plan before the collaboration asks for support from BNL. This document outlines our plan to investigate the most important issues related to the dEDM experiment as we currently understand them.

The main systematic errors are related to a) spin and beam dynamics and b) polarimetry. In addition to the systematic errors there are several issues regarding the injection and capture of the beam, transport of the beam to the polarimeter, etc., the solution of which might have an indirect influence on the systematic errors. We have therefore identified the major systems that need to be considered. Each is now associated with a team leader whose responsibility is to coordinate activities in their areas and to look for any major issues or conflicts. The major systems are:

Number	System	Team Leader
1	Slow Extraction	D. Lazarus
2	Spin Dynamics	Y. Orlov
3	Polarimetry	E. Stephenson
4	Lattice/beam dynamics	A. Luccio
5	Spin Coherence Time	V. Ptitsyn
6	Collective effects	A. Fedotov
7	Injection/capture system	M. Blaskiewicz
8	Mechanical alignment of ring	Y. Semertzidis
9	Source and beam preparation	A. Zelenski
10	Deuteron/Proton issues	B. Morse
11	DAQ	J. Miller
12	Low beta RF-cavities	I. Ben-Zvi

Table 2. The major systems and the corresponding team leaders are shown.

General systematic error strategy

In very general terms the major systematic errors related to spin dynamics originate from the presence of unwanted multipoles of the B and E-fields around the ring. The specifications required to control those fields are very stringent and several orders of magnitude beyond anything that has been achieved so far. We have therefore taken the approach of learning to live with them. We will first minimize them to very high accuracy (determined by their temporal stability) by using their effect on the spin (more sensitive) instead of measuring their effect on beam dynamics (less sensitive). Next we will rely on the different symmetries associated with the EDM and the systematic errors in order to decipher the EDM signal. The detailed outline of the plan to deal with these errors is shown in Section 1 below. We are planning to study these issues through intensive simulations that include all the possible uncontrollable field errors.

The polarimeter systematic errors are also potentially very damaging. In this case, the chief way to deal with them relies on the fact that adjacent beam bunches have EDM signals of opposite polarity, while the polarimetry errors have the same sign. The main tools for studying these errors are beam and spin dynamics calculations and simulations coupled with testing at existing facilities (such as KVI in the Netherlands and COSY in Germany) that currently provide polarized deuteron beams in the momentum range of interest. The detailed outline of this plan is given in Section 2.

The current list of potential spin related systematic errors includes:

1) Radial-vertical coupled oscillations
2) Collective effects
3) Instrumental alignment tolerances
4) Polarimeter instrumental errors

Our general strategy for studying systematic errors is to identify and exploit the specific symmetries of the method. Those are:

1) Our stored beam will be undergoing synchrotron oscillations in resonance with the g-2 frequency. Consecutive beam bunches will have 180° phase difference in their synchrotron oscillations while the polarization directions remain the same, meaning that their respective EDM signals will also have the opposite sign. A large range of systematic errors will have the same sign and will therefore be eliminated by properly subtracting the signals from consecutive bunches. Most of the polarimetry errors fall in this category.
2) Many systematic errors, including those from spin dynamics, have opposite symmetry to the EDM signal when the direction of the beam in the storage ring goes from clock-wise (CW) to counter-clock-wise (CCW).
3) Changing the ring lattice parameters in specific ways to make the systematic errors time dependent while keeping the EDM effect constant can effect a separation. This will provide a tool to identify many of the spin systematic error sources and eliminate them.
4) Eliminating the source of the main spin related systematic errors by modifying the ring response function with the help of nonlinearities is an important tool.

Section 1: Spin dynamics systematic errors plan

We are planning to focus a major part of our effort on studying the spin related systematic errors. We have developed several potential strategies to confront those errors and eliminate them. We need to evaluate the overall efficacy of each strategy in terms of effectiveness, least impact on the statistical power of the method, and implied constraints on the lattice parameters. Below we describe the potential errors and the different strategies we have developed so far to minimize them. It will take up to one and a half years after the BNL support materializes to check the effectiveness of our strategies and the optimization of the ring lattice.

Parasitic spin resonances at the g-2 frequency, and possibly at its higher harmonics, will be the main cause of systematic errors in spin dynamics. At the final level of our accuracy, $\delta d \sim 10^{-29} e.cm$, we can control them only by using polarimeter data, so the system (ring + polarimeter + correcting tools) will act as a precise EDM detector. We plan to investigate the following strategies to keep the precision at the needed level.

1. It is possible in principle to have a ring with self-cancellation of first-order parasitic spin resonances. This idea was briefly discussed at the recent EDM collaboration meeting on November 6, 2006. It was noted that perturbative B- and E-fields oscillating both with the g-2 frequency and phase may compensate each other in the spin resonance dynamics. Realization of such a possibility would greatly simplify the problem of overcoming or minimizing spin resonance systematic errors. Our plan is to find (analytically and by simulations) the most practical version of it.

2. Self-cancellation of spin resonances at the second and higher harmonics of the g-2 frequency is also needed. This requires $\alpha_p = 1$, since, at this value of the momentum compaction factor, spin possesses only the fundamental of the g-2 frequency. Therefore, the second and higher harmonics of the g-2 frequency, which will inevitably be present in the beam dynamics, will not resonate with the spin. We must and will design for $\alpha_p = 1$ and a long spin coherence time simultaneously because these two problems overlap. The main questions we plan to answer are (1) how many field nonlinearities have to be used, and (2) what is the required accuracy of these fields.

3. At this still preliminary stage, we also need to fully investigate and design an alternative method of parasitic resonance cancellation, namely, the method of two vertical tunes as described in [2]. In that article, we only considered the case of a single perturbation. The method needs to be extended to multiple perturbations. The main question to be answered is how to cancel the resulting side effects.

4. Under the condition that the first order effects are canceled, all second-order effects must be classified and investigated (analytically and by simulations), and the corresponding methods to cancel them must be found. Currently, with respect to these effects, we are just beginning.

5. The same holds with respect to the usual storage ring spin resonances.

6. We need to develop a skeleton program for automatic systematic corrections based on the polarimeter data for several different types of bunches simultaneously rotating in the ring.

The following is a way to cancel systematic errors caused by spin resonances in the case of multiple perturbations in a ring like our EDM ring, i.e., one that is not azimuthally homogeneous. Section 1.1 develops the idea proposed at the November 6, 2006 collaboration meeting. Section 1.2 lays out an old idea for artificially oscillating beta-functions of the EDM ring, thus avoiding what we still regard as the limitation of the two-tunes technique: that we cannot cancel more than one perturbation in an azimuthally non-homogeneous ring. Section 1.3 describes a method proposed at the March 5, 2007 collaboration meeting; it eliminates the systematic error at its source by designing the ring in such a way that the horizontal forced oscillations appear at half the g-2 frequency even though the synchrotron oscillations are at the g-2 frequency.

1.1 Using electro-magnetic quads to improve tolerances.

At the November 6, 2006 collaboration meeting, it was proposed to use electric quadrupoles (placed in the D=0 straight section) to partially cancel the spin resonance perturbations or, more precisely, their contribution to the parasitic signal. Subsequently, the use of electro-magnetic quadrupoles was proposed. In every such quadrupole, a kick on the transverse momentum, *p*, produced by the electric field of the electric quad is immediately canceled by the magnetic counter-kick produced by the magnetic quad. This means that the Lorentz force of such combined quadrupoles equals zero. But, of course, the torque acting on the particle spin is not zero. The idea of using such quads is based on this fact.

The idea is based also on the following understanding of the parasitic (i.e., non-EDM) spin resonances caused by skew field effects. Skew fields contain radial B_R-components. There also exist non-skew fields containing longitudinal B_L components which are assumed to be much smaller. Consider first a single B_R - perturbation localized at some azimuth. It simultaneously kicks the spin and particle momentum in the same vertical plane. Hence, the magnitude of the parasitic spin perturbation is proportional to the amplitude of the particle's forced vertical oscillations caused by this very perturbation. Our electromagnetic quadrupole (which we do not consider a perturbation) feels these vertical oscillations and produces its own kicks in response—acting, by design, only on the spin. Every such kick is proportional to the particle's vertical deviation at the quad position at the time it passes this quadrupole. This vertical deviation is proportional to the magnitude of the spin perturbation. Obviously, the proper choice of the electro-magnetic quadrupole gradients permits us to cancel that spin perturbation. Our simulations support this conclusion.

Suppose, now, that we have N locations of such dangerous perturbations. Then we will use N electromagnetic quads to cancel them. The values of the quad gradients will be found from N linear equations depending on the lattice parameters. With cancellation accuracy $\sim 10^{-4}$, we will improve the tolerances, for example, from $\theta \sim 10^{-14}$ to $\theta \sim 10^{-10}$ for the skew angles of the most sensitive lenses in the high dispersion (D) area. But this is still not sufficient. The necessary additional procedure (mentioned in [1]) is explained in the next section.

1.2. Separation of the parasitic perturbations from the EDM, and their final correction.

To correct a discrete set of N spin perturbations, including all B_R and some B_L spin resonance perturbations, we need at least N independent equations involving N observed data. Moreover, the signal from the perturbations must be separated from the EDM signal. Our equations will be linear with respect to perturbations because the perturbations will be very small. The separation of spin perturbations from the EDM is based on the idea of very slow oscillations (say ~ 0.01 periods/s) of the Courant beta-functions, different for different parts of the ring. We will use at least N different frequencies, and possibly different phases and amplitudes. It is important that beta-functions can be changed without perturbing the betatron tunes. Since the EDM is not sensitive to the beta-function changes, unlike the parasitic signal, the oscillating parts of the signal will carry information only about the perturbations.

To keep the betatron tunes ν_x and ν_y unchanged, we must change the lens gradients in such a way that (in the first approximation)

$$\oint \beta_{x,\, y} \Delta(\partial B / \partial x)_{lens} ds = 0\,, \tag{1}$$

where $\oint$ is the integral (or sum) over the ring and $\Delta(\partial B/ \partial x)_{lens}$ is the change of the field gradient of the lens located at azimuth *s*. For example, let the Courant beta-functions be equal at the azimuths
s_1 and s_2, $\beta_y(s_1) = \beta_y(s_2)$. If, during time interval δt, the changes of the gradients are opposite one another, $\Delta[\partial B(s_1)/\partial x] = -\Delta[\partial B(s_2)/\partial x]$, then (in the first approximation) the betatron tunes will not change during this time, and $\delta \nu_y = 0$.

The beta-functions change very differently. At an arbitrary azimuth *s*, in the first approximation,

$$\Delta\beta(s) = \frac{\beta(s)}{2\sin 2\pi\nu} \sum_{i=1}^{N} \beta(s_i) \frac{[\partial B(s_i)/\partial x] l_{lens}}{BR} \times \cos\left(2|\psi(s) - \psi(s_i)| - 2\pi\nu\right). \tag{2}$$

Due to the influence of the phase differences, the beta-functions change even when the betatron tunes do not.

Now, let us have *n* magnetic lenses in the D=0 section. In order to estimate the number of different versions of beta-functions we can produce, let us imagine that their gradients can take only two values, g_i and $-g_i$. Then we can construct
$N = 2^n - 2$ different beta-functions $\beta(s)$. (Here, -2 comes from the conditions (1) for not changing the betatron tunes.) In reality, we can oscillate every gradient between +*g* and -*g*. This means that we can calculate and correct many spin perturbations. Our N different frequencies will be applied to N different combinations of gradients. At the end of the run, we will Fourier analyze the spin signal.

1.3 Converting the horizontal forced oscillation frequency to half the g-2 frequency

Most parasitic spin resonances imitating the EDM are coupled to the coherent part of the vertical betatron oscillations. Such oscillations are induced by the coherent part of the radial betatron oscillations, which, in turn, are induced by the coherent oscillations of the particle velocities in our EDM resonance scheme. The sequence of events is the following:

(a) The particle velocities oscillate with exactly the g-2 frequency.
(b) Then, in any common storage ring, the particle radius oscillates with the same g-2 frequency.
(c) Due to some (inevitable) perturbative radial-vertical coupling, the particle vertical deviations also oscillate with the g-2 frequency.
(d) Finally, due to the focusing field gradients in the ring, radial magnetic fields met by the particles along their trajectories oscillate with the g-2 frequency, producing parasitic spin resonances which rotate spins in the vertical plane.

At the March 5, 2007 collaboration meeting, a new method was proposed to cancel all such resonances together, radically changing the sequence of events after point (a), above. In our specially designed ring, instead of (b) above, the particle radius will oscillate with the (g-2)/2 frequency, and perhaps also with higher harmonics, namely (2k+1)(g-2)/2 frequencies, i.e., always involving half integer g-2 frequencies.

This will be achieved by adding to the lattice a specially chosen sextupole magnetic field constant in time, plus magnetic dipole and quadrupole fields oscillating with the half integer g-2 frequency. The parameters can be chosen in such a way that the coherent radial deviations of the particle from the ideal orbit will be shifted and will oscillate with only half the g-2 frequency:

$$x \equiv (R - R_0) = a + b\ cos\left(\frac{\nu_a}{2}\theta\right). \tag{3}$$

where $\theta = 2\pi s / L$. In an azimuthally homogeneous ring with our additional elements, the *x* obeys the equation:

$$\frac{d^2x}{d\theta^2} + (1-n)x + \alpha x^2 + \varsigma x \cos\left(\frac{\nu_a\theta}{2}\right) + g\cos\left(\frac{\nu_a\theta}{2}\right) = \delta\cos(\nu_a\theta). \tag{4}$$

The term on the right hand side describes the external force induced by synchrotron oscillations, $\delta \propto (\Delta p / p)_0$. The third term from the left describes the sextupole field, the fourth the RF-quadrupole field, and the fifth the RF-dipole field. The usual gradient, $-n = R(\partial B / \partial x) / B$, can be chosen such that the particles' free oscillations (around the coherent forced oscillations (1)) are stable. Currently, we have estimated the required parameters for the case of a homogeneous ring, while neglecting the δ^2 terms.

If everything goes as planned, then instead of (c) above, due to perturbative radial-vertical coupling the particle vertical deviations will oscillate with the (g-2)/2 frequency, which is *not* resonant to the g-2 rotations. And, instead of (d) above, almost all radial magnetic fields met by the particles along their trajectories will oscillate with the non-resonant half-integer g-2 frequency, and not with the g-2 frequency.

As the result of such a design, most of the parasitic spin resonances will be eliminated altogether "by one shot." (In particular, the above mentioned requirement $\alpha_p = 1$ is no longer needed, so the statistical error may be reduced.) An exception will be the radial magnetic field of our sextupole, if and when it has a perturbative skew field. Inside such a sextupole, the particles will meet a radial magnetic field oscillating with the spin resonant g-2 frequency. However, this will be a single, isolated spin resonance source, and we know well how to cancel such isolated sources, as described in Section 1.1.

We have described several strategies for eliminating the main spin-related systematic errors. We need to test those strategies in the presence of multiple perturbations, including lattice element misalignment, B- and E-field multipoles and collective effects. We also need to study how the choice of specific strategies influences other important parameters of the experiment such as the spin coherence time, the permitted tune shift and tune spread due to collective effects.

Section 2: Polarimeter test plan

The response from the Program Advisory Committee suggested that we use existing facilities with polarized deuteron beams to test the concepts behind the polarimeter for the storage ring EDM search, with the goal of demonstrating the feasibility of the polarimeter for this work. Since this response became available, two planning meetings have been held. The first was at the KVI-Groningen on December 5-7, 2006, and involved collaborators from the KVI, Italy, and the USA. At this meeting we discussed possible running at COSY-Jülich and at the KVI. Four members of this group then paid a visit to COSY on February 14-16, 2007 to discuss detailed planning with the staff of COSY and to inspect the ring and detector systems available there. As a result of these discussions, we have identified four major components in the development of the EDM storage ring polarimeter feasibility study.

1. The PAC report asks that we demonstrate that the polarimeter is free of systematic effects at the level required for a sensitivity of 10^{-29} e·cm. In the short term, this may not be achievable because the amount of data required to reach the statistical sensitivity level of the final EDM search is very large and there are constraints on the beam time available at user facilities. Instead, we propose to identify a set of error driving terms (shift of position or angle, spot size, divergence, velocity modulation, difference in up and down polarization magnitudes, rate effects, dispersion, etc.) that may appear singly or in combinations, as well as a set of strategies (comparison of plus and minus effects, cancellation in analysis, etc.) to cope with them. For some mock polarimeter configuration for which we understand the cross section and analyzing power angular distributions that give rise to the observed polarimeter rates, we will measure the sensitivity of the polarimeter results to various combinations of driving terms. These sensitivities are just the partial derivatives of the polarimeter cross section and analyzing power with respect to any driving term. At the KVI, we would like to use an existing polarimeter in the main beam line to measure the sensitivities for a polarimeter configuration as similar as possible to our polarimeter using detectors already in place. The driving terms will come from carefully calibrated manipulations of the beam. A correct prediction of these sensitivities would demonstrate our ability to estimate such effects. We would then investigate and measure those systematic effects that are likely to impose significant constraints on the design or operation of the storage ring. This will demonstrate that we have in place a method that will allow us to estimate reliably the effects of such driving terms on the final EDM polarimeter measurements. Beam time for such studies is already available and approved as part of a Letter of Intent that was submitted to the KVI-Groningen in 2004. We expect that running can be scheduled between now and the end of 2007 with both unpolarized and polarized deuteron beams, using detectors from the present KVI In-Beam Polarimeter that have been modified to observe deuteron-carbon scattering in conditions similar to that for the EDM polarimeter. These studies may be extended to COSY at a later date.

2. The cooled storage ring COSY at the Forschungszentrum Jülich offers the environment most like that for the deuteron storage ring to be used in the EDM search. There are also a number of detector stations around the COSY ring, including the EDDA detector which has been used recently as a deuteron polarimeter by the SPIN@COSY Collaboration based at the University of Michigan [4]. So a second thrust of this study will be to make use of this polarimeter to come as close as possible to the running conditions on the EDM ring and to observe what, if any, systematic effects emerge as issues with a measurement of the beam polarization. This will involve the following efforts:
    a. Tests using the EDDA detector system will be used to demonstrate the viability of slow extraction of the beam via Coulomb scattering from a gas jet target followed by interception of the extracted flux by a thick annular carbon target that is just ahead of the polarimeter detectors. Such a scheme in which the annular carbon target is also the limiting aperture in the storage ring should increase the efficiency of such a polarimeter to better than 1% and make it possible to examine the time dependence of the polarization of the beam with good precision during a store that lasts up to 1000 s.
    b. We will demonstrate that it is feasible to rotate the polarization from the vertical to the horizontal plane and to measure this polarization directly. For this, we need to understand the constraints on an RF dipole system that would be used to produce such a precession so that an appropriate system can be implemented. Second, the data acquisition system for the EDDA detectors needs to be upgraded to allow for the measurement of turn count along with the data from the detector system. In parallel, we need to make every effort to lengthen the polarization coherence time of the deuteron beam in the COSY lattice.
    c. Either using existing or new RF equipment, a forced synchrotron oscillation should be imposed on the deuteron beam within the momentum acceptance of the COSY ring (about 10^{-3}) so that the sensitivity of the polarimeter to such oscillations can be investigated (in conjunction with other driving terms as noted above). This tests directly the main scheme we hope to use for the elimination of polarimeter systematic errors, the subtraction of effects on adjacent beam bunches whose EDM signals arise from opposite phases of the synchrotron oscillations with respect to the g-2 precession. For this test, it is not necessary that we drive the system at the g-2 frequency, only that the phase of the forced synchrotron oscillations be know.
3. Except for reports on deuteron polarimeters at Saturne, there is essentially no information on the cross section and polarization dependence of deuteron-induced reactions in the momentum range between 1.0 and 1.5 GeV/c. The Saturne results did not separate the effects of deuteron elastic scattering from inelastic scattering and deuteron breakup. The latter process has essentially no polarization dependence, as demonstrated by our earlier studies between 76 and 113 MeV at the KVI. Better data are essential to the design of our polarimeter since it is likely that a better optimization of the detectors to record predominantly elastically

scattered deuterons will result is a doubling of the analyzing power of the polarimeter. Such an enhanced analyzing power is important both for the sensitivity of the search and the suppression of systematic errors. The best detector for the purpose appears to be the forward tracking system of the newly-installed WASA detector.

4. The location of the polarimeter on the EDM ring is not yet final, and will in any event have to deal with tight geometries and the large beam sizes needed for the size of the phase space used by the forced synchrotron oscillations. For this reason, we need to investigate new, fast tracking and readout detector systems (such as MRPC) that may need to be a part of our consideration of the design of the polarimeter. We plan to make use of the COSY ring as a test site for such detectors, eventually leading to the test of a prototype EDM polarimeter.

The next proposal deadline for COSY is March 21, 2007. At this time, we intend to submit a proposal that describes the long-term objectives of the EDM polarimeter development using the storage ring COSY as well as the short-term running time objectives. The earliest running time that is available at COSY starts in September, 2007. During 2007, it is likely that only a test of the double polarimeter target will be practical (item 2a). None of the detector systems at COSY would be available for deuteron-carbon scattering data collection within this year.

Further comments on various COSY items are included below.

Part 2a: Annular carbon target tests

The EDDA detector was constructed for the purpose of detecting p+p and d+p scattering from a polarized atomic beam target that crossed the stored polarized beam in COSY. This experimental program has been completed. Since then, the SPIN@COSY Collaboration has used this detector arrangement in scaler readout mode with a fiber carbon target to measure deuteron beam polarizations in the storage ring. These polarizations are a part of a series of studies on the use of a frequency-ramped RF dipole to flip the sign of the polarization of the stored deuteron beam. This measurement already relies on the spin-dependence of forward deuteron-carbon scattering, the same process that we wish to exploit.

The carbon fiber target is brought into the beam on a target ladder mounted on a motor drive. Two such drives exist, one above and one below the beam. By substituting the target forks with halves of the annular carbon target, we can have our target available with essentially no hardware construction. It is important to be able to retract the target during initial filling, cooling, and ramping of the ring; a split target makes this possible.

At present, there are already two gas jet targets in the COSY ring, one at the small-angle scattering COSY-11 setup and another at ANKE. So long as the annular target is the limiting aperture in the ring, then it is not necessary that the Coulomb scattering target be immediately upstream of EDDA. Any place in the ring will suffice, as deuterons will be transported to the carbon target even though they have larger than normal betatron oscillations. Discussions are underway for the location of spin filtering tests in the PISA scattering chamber area. This location, which is just upstream of the EDDA detector, will eventually house a polarized atomic beam source. This will provide sufficient pumping at this location, and the installation of a thin gas jet target nozzle is a relatively minor task.

(We will not proceed with further parts of this item until we can provide the COSY PAC with detailed simulations of the RF dipole effects that demonstrate a procedure for producing a horizontally polarized deuteron beam.)

Part 2b: Deuteron-induced reaction measurements

We considered three in-place detector systems as candidates for making measurements of a broad range of deuteron-induced reactions at COSY. In all cases, there was not readily available a scheme for measuring the deuteron beam current; thus we will need to consider other means (such as interleaving carbon measurements with measurements from a CH_2 foil and comparing to independent d+p elastic scattering measurements) for obtaining a measure of the luminosity.

The analyzing power is derived from measurements with the ring filled alternately with vector polarized deuteron of one spin projection, then the other. Again, the lack of an adequate means of measuring the relative luminosity means that any analyzing power measurement depends on the observations of the cos φ dependence in the cross section that appears when the beam is polarized.

The best choice for our needs appears to be the WASA detector, a 4π arrangement where most of the solid angle is covered by a straw tube tracker and CsI calorimeter. In the forward direction (inside 17°) there is a different tracker consisting of a series of plastic scintillators and wire chambers that both mark the direction of charged particles and, except at the highest deuteron energies, stop them in a series of scintillation detectors. By providing an additional such layer, complete energy measurements on all deuterons would become possible. Such an arrangement can be used for particle identification as separate measurements of the particle energy and rate of energy loss (dE/dx) are available. One concern with this arrangement is that the reaction losses for 1.5 GeV/c deuterons can be as high as 40%. However, the fact that the detector is divided into a series of scintillators means that such losses, especially for the elastically scattered deuterons, are straightforward to identify and quantify.

To date, the WASA detector has relied on frozen hydrogen pellets as the target material. For our studies, the pellet system would need to be replaced by a ladder that contained a series of thin carbon fibers. Such a system, along with its controls, must be approved by the WASA collaboration and then engineered so as not to interfere with the existing WASA equipment. It is unlikely that this could happen before sometime in 2008.

Schedule and Budget

The schedule for the spin related systematic errors after the support from BNL materializes is:

- Use a plausible dEDM ring lattice to study the effect of multiple systematic error sources located randomly around the ring. Test the accuracy of the software used to simulate the effects, its simulation speed and techniques to improve it.

Determine the sensitivity level of the two tune technique with and without the presence of many error sources around the ring. The estimated required calendar time is three months - summer, 2007.

- Add fields generated due to collective effects, in a dynamic fashion, i.e. add time dependence (collective effects depend on the beam intensity and therefore they will be changing from early to late times after beam injection). Estimated calendar time to achieve a reliable simulation of the collective effects is two months - fall, 2007.
- Study the case of varying the amplitude of the ring beta-function around the ring. Do this without changing the vertical betatron tune in the dispersive part of the ring. Study the Fourier analyzed signals and the statistical sensitivity of fitting for the systematic errors in the final data set. The estimated time to calculate the parameters of such a ring and understanding its errors is four calendar months-winter 2007/2008.
- Study the ring where the horizontal forced oscillation frequency is modified to half of the g-2 frequency in the presence of synchrotron oscillation at the g-2 frequency. The estimated calendar time for completing this study is six calendar months-spring/summer 2008.

The schedule for the polarimeter tests as presented in more detail section can be summarized as follows:

- Use EDDA polarimeter with annular carbon target to measure efficiency – 10-day run in fall, 2007.
- Make carbon fiber target for WASA, measure d+C cross sections and analyzing powers – 17-day run in winter, 2008.
- Install new RF dipole (if we need it), improve EDDA electronics – 2 times 10-day runs in spring, 2008.
- Modify COSY RF (if needed) and add forced synchrotron oscillations to study – 10-day run in fall, 2008.

It is expected that we will start making significant progress as soon as BNL support materializes. Overall we need support for two person-years for the next two years, by which time we expect to have the proposal ready. Specifically we need $195 K to support visitors and (mostly) locals to work on the spin related systematic errors. We also need $75 K to support (mostly) visitors and locals to work on the beam capture, collective effects, and interface with the polarimeter.

The polarimeter hardware requirements are estimated at the $240 K level, which include incremental investment in electronics and mechanical equipment to fully utilize the presently available detectors at COSY and KVI. In addition we need $60 K in travel support for running the tests at COSY and KVI for the next two years. The total required sum to support the dEDM R&D is $570 K for the next two years.

Conclusion

We have identified a number of potential sources of systematic errors and we have outlined a general program to study them as requested by the PAC. We have also identified a number of promising ways to handle these systematic errors. Carrying out the proposed program of simulations and other studies will require substantial manpower. At present, we have the part-time effort available from existing collaborators. In order to solve the challenging issues which have been raised in a timely manner, it is essential that we receive the requested support.

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