Sub-work packages, Polarimeter Effort

Ed Stephenson, 10 April 2017

Introduction

Experimental feasibility studies related to mostly a deuteron polarimeter have been underway beginning at the KVI in Groningen in 2004. This work was initiated to answer two persistent questions concerning the feasibility of a storage ring EDM search:

1. Is it possible, in a storage ring, to achieve beam polarization errors as small as p ~ 10^{-6}? A demonstration run at COSY in 2009 showed a general method of calibrating polarimeter errors due to rate and geometry changes and using information from the data to make corrections in real time [1]. In the process, efficiencies consistent with those needed for the EDM search were obtained with thick carbon targets and slow beam extraction onto those targets.
2. Can the horizontal plane polarization lifetime be extended to 1000 s? In the course of this study, the main depolarization mechanism (spin tune shift due to betatron oscillations) was identified. It was shown [2] that the tuning of sextupole fields can cancel this mechanism (using a time-marking system [3] to permit studies of the rapidly rotating in-plane polarization in place of a frozen spin system). In addition, real time measurements were used to adjust the spin tune and its phase through feedback from the polarization measurement to the rf cavity frequency.

At present, work continues on the use of dense (LYSO) crystal scintillators as standard polarimeter detectors, and a data base run has been completed that will provide the information upon which a detailed engineering design of the polarimeter may be based. Further refinements concerning targetry, spin effects, and systematic effects are still underway. The maturity of these results will make it straightforward to describe the EDM polarimeter and how it will function.

[1] N.P.M. Brantjes *et al.,* NIM A **664**, 49 (2012).
[2] G. Guidoboni *et al.*, PRL **117**, 054801 (2016).
[3] Z. Bagdasarian *et al.*, PR STAB **17**, 052803 (2014).

Writing sub-work packages

The request for sub-work packages may be answered for either writing tasks or continuing developments whose results may be incorporated into the final feasibility report.

I propose that I take the lead with the writing task, asking for help and material as needed. Irakli Keshelashvili will assist with information about the LYSO crystal system and the test results conducted with the extracted beam at COSY. In addition to the calorimetric detectors, tracking detectors are under active development at both Demokritos, Greece and Daejeon, South Korea. I have some material already about all of these subjects, and will coordinate about what to include in the draft report.

Development sub-work packages

The developments currently underway are summarized in a chart (attached) and explained in more detail below. The number of projects suggested for 2018 is probably too ambitious, given the constraints on running time and preparation effort. As we go, we will continue to evaluate which of these looks to be the most promising and within our grasp.

[A] Deuteron data base

This package covers the work currently underway to analyze the data from the 2016 data base run. Volker Hejny and Maria Zurek are coordinating. Others, including Fabian Müller, Iza Ciepal, and Aleksandra Wronska, are providing supporting analysis. Calibration is underway. Once that and particle identification are completed, an unfolding needs to be applied to eliminate reaction tails in the spectra and to prepare the data for use in a Monte Carlo event generator suitable for use in GEANT. With that in place, various designs may be explored for combinations of calorimeteter, energy loss, and tracking detector arrangements along with absorbers to obtain the optimum design for a deuteron polarimeter. This is shown as package B.

Prior to the running of the precursor with polarized beam, we need to know how to configure the WASA Forward Detector as a polarimeter using a more restrictive "quick" trigger (to reduce sensitivity to deuteron breakup) and scaler readout. This may involve a search for the beam energy that best optimizes the polarimeter figure of merit (and is consistent with the limits on the available detectors).

[B] Deuteron polarimeter (mock-up)

One goal worth considering would be the construction of an EDM polarimeter mock-up to be tested toward the end of 2018. It would include the detector/absorber configuration from the data base analysis and any new target configurations determined to be useful (see packages E and F). It would most likely use the LYSO crystal setup envisioned for installation at the COSY ANKE location.

Targets other than carbon would be examined.

[C] Proton data base

The South Korean group is particularly interested in pursuing the proton EDM ring and would like to have a proton polarimeter data base to constrain their design. Such a proposal was postponed earlier due to the commitment of COSY for upgrading the beam optics and control and the preparation of the precursor Wien filter and experiment. It needs a serious commitment of persons from South Korea, and in particular a student who would be resident at COSY and work full time on this effort. Otherwise it follows the pattern of the deuteron data base study and would make use of the WASA Forward Detector.

[D] Tracking detector testing with external beam

Two groups, one in South Korea and another at Demokritos is Greece, have expressed an interest in providing the tracking detector for any EDM polarimeter. The Demokritos group has built and tested drift chamber sections using the muon test beam at CERN. The Korean group is planning to construct a GEM detector system using components and DAQ systems patterned after CERN electronics and software. Both groups have expressed an interest in making a test in the fall of this year. The time for that may well be in the last 3-month cycle in conjunction with the next iteration of Irakli's LYSO crystal tests. These groups will need to arrange to have their equipment shipped to COSY and follow up with longer visits for

installation and testing. After the tests have been analyzed, preparation can get underway for the polarimeter mock-up experiment, including one or both tracking systems.

Also under development is a ΔE (energy loss rate) detector for use just ahead of the LYSO crystals. By dividing the scintillator into a series of overlapping triangles, energy sharing ratios may be used to locate the track with more precision, augmenting the information from the tracking detectors.

[E] Strip target testing and optimization

Tests with a moving strip target produced polarimeter efficiencies (EDDA detector) that were within an order of magnitude of those obtained with a thick carbon block target. The carbon block has the disadvantage that it samples only the halo of the beam and extraction of the beam may create other difficulties for the EDM experiment and diagnostics, including other polarimeters located in the beam. The idea here is to have a short run in which we explore the space of target thickness, target speed passing through the beam, and RF cavity voltage (involved with recovering the energy lost in passing through the target). We would search for the point of best efficiency for the polarimeter (probably the quick trigger WASA Forward Detector) as an alternative to the carbon block target.

Prior to the run we need to construct an assembly that allows a well-controlled study of strip targets passing through the beam. One possible design would be to attach a series of such targets to a rotating wheel. With sufficient spacing, multiple targets could be included with different thicknesses and/or widths and they would act independently on the beam. A mechanical readout would be needed to inform the DAQ about target location and identity.

Such a system would open the possibility to consider multiple polarimeters on the EDM ring.

This system would be a part of the mock-up test, if it proved successful.

[F] Pellet target testing and optimization

In a scheme similar to that for the strip target, pellet (diamond) targets could be tested. It is expected that there will be more engineering challenges realizing this system and a readout capable of locating the pellet at all times, so it is not clear whether this would be ready for the mock-up test in 2018.

It is hoped that a student will be found who can undertake this project as a thesis.

[G] Further spin manipulation tests

There are a number of open questions that remain from the runs aimed at demonstrating a long spin coherence time for an in-plane polarized beam. They include:

1. If the sextupole correction fields are capable of correcting orbit lengthening's contribution to a shorter polarization lifetime, to what extent is it necessary to electron cool the beam for an EDM experiment? Tests with COSY suggested that the electron cooling could be scaled back with no damage to the polarization lifetime. But the test without cooling failed because the beam (on first harmonic) became too long and polarization was lost in the precession from vertical to horizontal at the start of the test. Such a problem could be corrected with barrier bucket technology, and the test repeated. If successful, it might allow the design at CERN to proceed without a preparatory storage ring for cooling the beam.
2. On the other end of the electron cooling spectrum of possibilities, it has been suggested that running with electron cooling on continuously results in a significantly longer in-plane polarization lifetime. Only a few runs relevant to this question have been taken and the results are ambiguous.

It would be important to couple such a study with calculations of the polarization lifetime in the presence of the internal beam mixing associated with electron cooling (see project I).

3. Stochastic cooling may be less harmful to the EDM experiment than electron cooling (due to the reduced amount of field necessary to produce cooling). It also offers the prospect of independent cooling along each of the three spatial dimensions. If sufficient resources were available to create a cooling system for lower momentum, then these things could be tested with the COSY beam.
4. The tests reported in the PRL for long polarization lifetime were taken with beam of less than 10^9 particles/fill. The EDM experiment nominally needs much more beam. But the experience in 2013 and 2014 with higher beam currents was not satisfactory. Other effects, some collective, were seen with the beam and simple results with extraction on a carbon block target did not happen. We need some time to increase the beam, with good diagnostics, document what happens at larger currents, and look for ways to mitigate the problems.

[H] CW/CCW operation

In 2016, a number of people (Marcel Rosenthal, Yann Dutheil, Mei Bai, Valentina Rolando, and I) worked on the question of whether or not CCW operation of the COSY ring might be used to test the notion that a CW/CCW (with a "perfectly" reproduced orbit, fields, etc.) comparison could make the EDM signal appear in principle, even in the presence of ring imperfections or stray fields. Those calculations were encouraging (even though some questions of definition remain to be resolved).

These studies raised the question of whether a more insightful analysis of machine errors might lead to other results useful for the EDM and precursor experiments.

It appears that all meaningful field errors can be resolved into two components corresponding to longitudinal and sideways rotations in the ring. If this is the case, then the addition of two independent "errors" may be used to cancel all such ring errors. These could be, for example, weak solenoids located in different parts of the ring. If such a scheme could be used to cancel ring systematic errors, leaving only the EDM signal, then this would relieve the ring design of an excessive dependence on geometric perfection to realize a workable experiment. Such a possibility needs to be explored in detail.

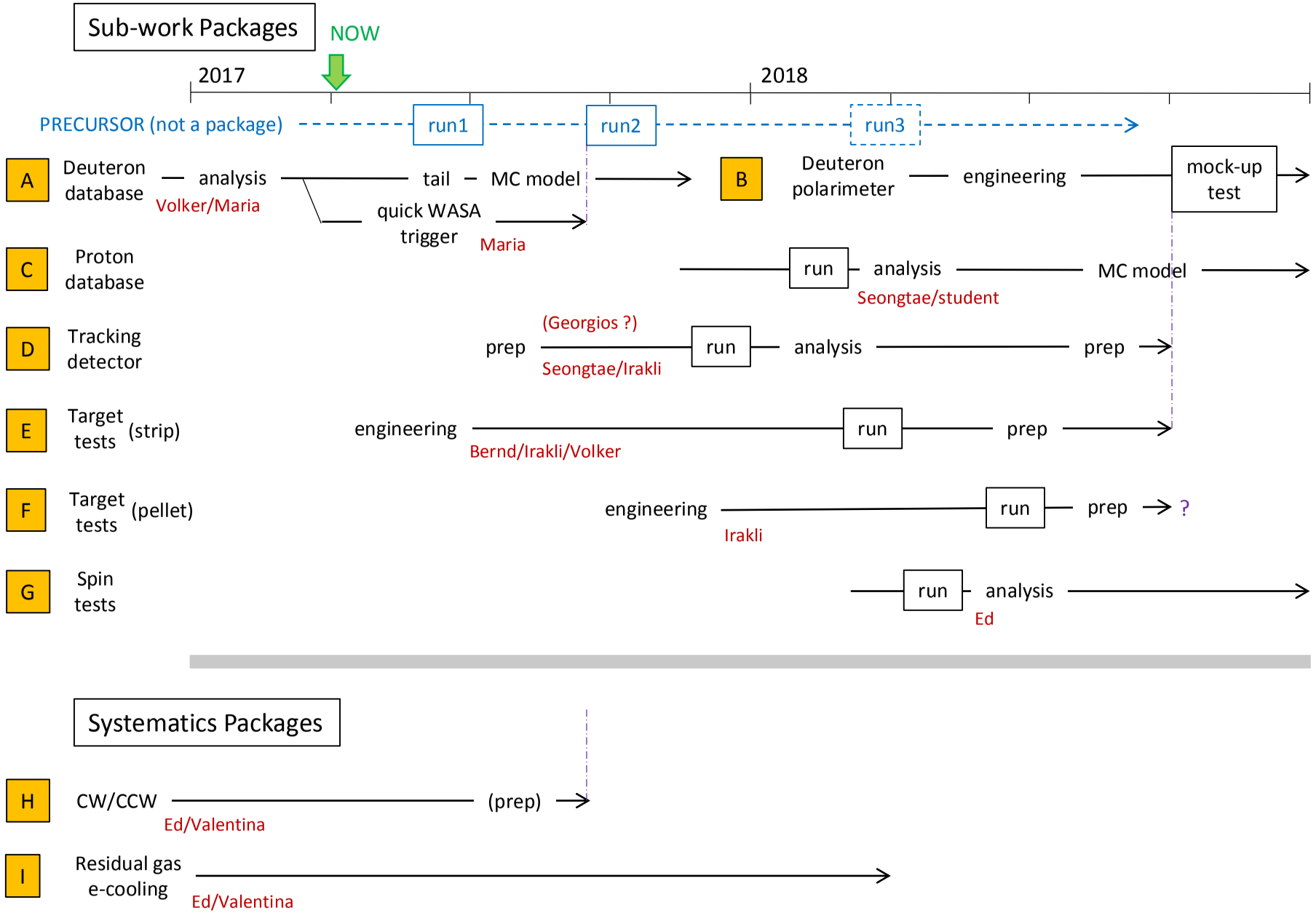
In addition, ring imperfections have been shown to generate a fake EDM signals in which the vertical polarization components accumulates in the precursor experiment. In order to be able to argue that the precursor experiment is sensitive to the EDM, the feedback must be calibrated so that it is known that the polarization is longitudinal when the Wien filter field is at its maximum. An independent calibration can be made if a strong enough solenoidal field is applied in the straight section opposite the Wien filter so that a vertical polarization accumulation is seen. In that case, the best operating point occurs with the feedback phase is set to remove the accumulation due to the solenoid. This needs to be ready for test by the second precursor experimental run.

Work is needed to finalize and write up these results for the group.

[I] Modeling of background gas and electron cooling effects on polarization

From experiments so far, the effects of background gas on the spin studies made at COSY seem modest to the point of being ignored. This may not be true for the EDM experiment since processes such as energy loss create effects that favor beam tails on one side of the beam. A calculation is being developed that includes such effects in the "no lattice" model. A left-right asymmetry might arise, for example from the interaction of such a tail with a residual tensor component in the beam through the effects of a T_{21} analyzing power.

In addition, electron cooling effects on the polarization lifetime are not well studied. A model is needed in order to be able to separate effects of the cooling from other things that may happen during a beam test (see item G).


Sub-work Packages
NOW
2017
2018
PRECURSOR (not a package)
run1
run2
run3
A
Deuteron database
analysis
Volker/Maria
tail
MC model
quick WASA trigger
Maria
B
Deuteron polarimeter
engineering
mock-up test
C
Proton database
run
analysis
Seongtae/student
MC model
D
Tracking detector
prep
(Georgios ?)
Seongtae/Irakli
run
analysis
prep
E
Target tests (strip)
engineering
Bernd/Irakli/Volker
run
prep
F
Target tests (pellet)
engineering
Irakli
run
prep
?
G
Spin tests
run
analysis
Ed
Systematics Packages
H
CW/CCW
Ed/Valentina
(prep)
I
Residual gas e-cooling
Ed/Valentina